

An Analysis of Greenhouse Gas Mitigation and Carbon Biosequestration Opportunities from Rural Land Use

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An Analysis of Greenhouse Gas Mitigation and Carbon Sequestration Opportunities from Rural Land Use, edited by Sandra Eady, Mike Grundy, Michael Battaglia and Brian Keating

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Executive summary

This CSIRO report provides an in-depth assessment of the greenhouse gas (GHG) sequestration/mitigation potential likely to be achieved through change in rural land use and management, based on a review of current knowledge and consultation with a cross-section of scientists and land management experts. The focus is on Queensland but in most instances national potential is also estimated.

The report revisits the Garnaut Review (2008) estimates¹ for terrestrial greenhouse gas sequestration – in more detail, with a discussion of implementation issues, risks and interactions between options. The review was requested by the Queensland Premier's Council on Climate Change – as a technical input to policy development. The report confirms that there are a wide variety of options for sequestering or mitigating GHG emissions through changed land use and management; the options studied were based on the Garnaut Review categories with some changes in definition and emphasis.

This report demonstrates that Australia has the opportunity to offset a significant proportion of our GHG emissions, by storing carbon in the landscape and changing the emissions profile from rural land use. Thus, the broad thrust of the Garnaut Review is supported – within Queensland an overall **technical potential** of 293Mt CO₂-e/yr for GHG abatement was estimated, with 140 Mt of this potential being assessed as **attainable** with concerted efforts in technical and management changes, policy adjustment and shifts in current land management priorities. It must be recognised that these estimates contain a combination of biological, technical and implementation uncertainty.

In 2007, total GHG emissions for Queensland were 182 Mt CO₂-e/yr, so the attainable estimate of 140 Mt CO₂-e/yr (77% of the state's emissions) indicates that terrestrial GHG management could play a key role in emissions abatement over the next 40-50 years. A complete set of national estimates was not undertaken but where they were available the results suggest a similar outcome would be achieved.

For Queensland, the largest quantities of abatement are associated with options that cover forestry activities such as carbon forestry (including biodiversity plantings), commercial forest plantations, and reduced land clearing/managed regeneration. Estimates are that these options may account for approximately 105 Mt CO₂-e/yr, and importantly have relatively low barriers to implementation.

Across many of the other studied options, it is clear that enabling technology and appropriate policy incentives could lead to a significant reduction in emissions or increased carbon sequestration. Changes in agricultural practices to build carbon reserves in agricultural and rangelands systems could yield 26 Mt CO₂-e/yr while substitution of fossil fuels with renewable bioenergy could reduce emissions by 9 Mt CO₂-e/yr.

Many of these options are most effective over the next 40–50 years as increased levels of saturation over time will reduce returns on investment in sequestration. Nevertheless, they offer a key component of GHG management within a framework of more comprehensive abatement policies and practices, especially in the near term. Although carbon storage in landscapes will saturate, the production of renewable biomass feedstock for biochar and bioenergy provides the potential for continued mitigation post 2050. However, an integrated approach to GHG abatement across agriculture, energy and transport sectors is still important; sequestration has large natural uncertainties compared to achieving similar abatement through a reduction in the burning of fossil fuels.

There were significant differences to the Garnaut estimates for individual abatement options; in most cases these were due to definitional differences but they also occurred because the study brought in more recent analyses and models. These differences are discussed in the report. In this study, as with the Garnaut Report, estimates for soil carbon storage were only made for cropping systems and rehabilitation of rangelands. Soil carbon changes associated with enterprise change (crop to pasture, pasture to trees) were not considered. Although major additional soil carbon storage could theoretically be achieved by such land use change, the potential rates of storage and areas of land are difficult to define with the current state of knowledge.

¹ Garnaut, R (2008) The Garnaut Climate Change Review: Final Report, Cambridge University Press, Port Melbourne. <http://www.garnautreview.org.au/index.htm> – ch.22

The report discusses each option in detail – this allows an evaluation of the scope of the option, the level of uncertainty, risks and barriers to implementation and the current status in GHG accounting. Also discussed in the report are the investment and management actions required for implementation, the relative feasibility and attractiveness, the regional applicability of different options and the economic, social and institutional issues associated with land use change. However, the report does not quantify the relative cost effectiveness of the different mitigation and sequestration opportunities.

The analysis found that forestry options are likely to be the easiest to implement given the current level of technical knowledge and certainty about levels of carbon storage. The most difficult to implement are the options that apply to complex eco-systems and where there is a high level of uncertainty about carbon storage, for example, regeneration of rangelands and mulga.

International and national policy frameworks will also influence implementation. Some options such as carbon forestry are covered in a clear manner in the Kyoto Protocol and the proposed Carbon Pollution Reduction Scheme (CPRS), while other options, where carbon is stored in the soil or in regenerated native vegetation, are not readily accommodated in the current frameworks in a manner that best suits the Australian environment.

The goal of this report was to better quantify the magnitude of sequestration/mitigation opportunities so that on-going policy development can be undertaken with knowledge of the likely quantum of GHG abatement offered by land use change.

Despite the initial focus on Queensland policy needs, the published document has broader relevance to national carbon emissions reduction strategies. Of Australia's total emissions in 2007 (597 Mt CO₂-e) some 88 Mt came from agriculture and 77 Mt from deforestation, including land clearing for agriculture. Thus abatement through rural land use change is valuable despite the current uncertainty around estimated values and complications with the inclusion in international GHG accounting frameworks. This report provides underpinning information on the nature of these options and points to the key literature. It provides an important basis for national discussions on the potential for terrestrial GHG sequestration and the dimensions involved in its pursuit.

The options studied in the report are detailed in the **Summary Table** on page 12. Many options overlap – an investment or development of one option will limit the potential for development of others. This overlap has been identified, where possible, and overall figures adjusted to account for competition for resources for GHG abatement.

The report seeks to extend the analysis beyond the technical potential identified in the Garnaut Review to include concepts of what is attainable given concerted efforts in technical and management changes, policy adjustment and shifts in current land management priorities. The options for sequestration/mitigation are qualitatively different so a consistent quantitative estimate of attainable levels was not applied across options. In each case the assessment contained a combination of biological, technical and implementation uncertainty. An economic dimension is clearly part of this assessment but was only explicitly applied in some options. For example, it was assumed that the price for carbon would largely influence land use change to carbon forestry and this option was modelled with a carbon price of \$20/tonne, whereas the attainable level of mitigation for livestock was assumed to be largely a function of the availability of appropriate technology.

Much of the terrestrial sequestration potential involves spatially extensive activities, where small contributions per unit land area collectively contribute significantly through application over large areas. This extent means that their widespread adoption, as might occur by their inclusion in the proposed CPRS and a high carbon price, could see them transform rural landscapes with substantial benefits; alternatively adverse outcomes for the environment, productive capacity, rural livelihoods and commodity supplies are possible without a planned and systemic approach to implementation. These cross-cutting issues are identified in the document and discussed. To achieve the levels of GHG abatement assessed as attainable in this report would require changes in policy and economic settings and in the technical toolkit. Some change will be possible within Queensland, some will require adjustment to national settings and some are dependent on international developments, especially in the carbon accounting framework for post-Kyoto climate agreements.

Summary Table: Annual GHG sequestration/mitigation (Mt CO₂-e) both nationally and within Queensland over a 40 year time horizon (2010-2050) using estimates from Garnaut (2008) and independent analysis (shaded options are subset of another option or compete for resources with another option and are not included in total figures).

Option	Garnaut (2008)	Estimates from this study (Mt CO ₂ -e/yr)		
		National Potential	National Potential	Queensland Potential Attainable
AGRICULTURE				
Rehabilitate overgrazed <i>rangelands</i> , restoring soil and vegetation C-balance	286	100*	35	18
Rehabilitate mulga lands, restoring soil and vegetation C-balance (subset of <i>rangelands</i>)	250	20*	4	2
Mitigation of emissions from <i>savanna</i> burning (Kyoto-compliant gases)***	5	13*	2	1
Build soil carbon storage and mitigate N ₂ O emissions for cropped land (land use change not considered)	68	25*	4	0.4
Reduce livestock enteric emissions and structural change in industry***	16	26	11	7
GHG sequestration/mitigation for Agriculture (accounting for overlap of options)		164	52	26
FORESTRY				
Change land use to <i>carbon forestry</i> (primary goal is carbon sequestration)	143	750*	153	77
Biodiversity - Implement <i>biodiversity plantings</i> as carbon sink (primary goal is promotion of native biodiversity; subset of <i>carbon forestry</i>)	<i>Not estimated</i>	350	56	28
Carbon storage in post-1990 <i>plantations</i> (primary goal is commercial biomass harvest; competes for resources with <i>carbon forestry</i>)	50	400	97	2
Increase carbon banks in <i>pre-1990 eucalypt</i> forests	136	47*	21	21**
Carbon positive management of <i>regrowth</i> vegetation and remnant forest (reduce land clearing)	63	56	38	7
GHG sequestration/mitigation for Forestry (accounting for overlap of options)		853	212	105
BIOENERGY***				
Substitution of fossil fuels with biofuel/bioelectricity from 1 st gen. biomass resources	44 (mix of 1 st , 2 nd gen sources)	Not estimated	5	1
Substitution of fossil fuels with biofuel/bioelectricity from 2 nd gen. biomass resources		Not estimated	24	8
Stabilise organic carbon in <i>biochar</i> and store in soil (sugar cane biomass only; competes for resources with 2 nd gen. biomass)	<i>Not estimated</i>	9	8	4
GHG sequestration/mitigation for Bioenergy (accounting for overlap of options)		Not estimated	29	9
Total GHG sequestration/mitigation for Queensland (accounting for overlap of options)			293	140

* Where estimates are significantly different between the Garnaut Review and this study the reason is often definitional and related to the area of land, however in some instances the estimated carbon sequestration rates also varied.

** The potential and attainable are equal in this instance as the forest is an existing resource.

*** These options will be continuous in their sequestration/mitigation while other options will saturate over time.

Sandra Eady, Michael Grundy and Michael Battaglia

1.1 Introduction

In 2007, Australia emitted 597 Mt CO₂-e of greenhouse gases (GHG) from all sectors (Department of Climate Change 2009²). Of this, the agriculture sector contributed 88 Mt CO₂-e and a further 77 Mt CO₂-e was emitted from deforestation, including land cleared for agriculture. The pattern is similar for Queensland. Of total emissions of 182 Mt CO₂-e in 2007, 26 Mt were from agriculture and 50 Mt from deforestation. This relatively high level of contribution by agriculture argues for this sector to be included in efforts to reduce national emissions.

Although agricultural sources are relatively high, Australia also has a greater potential for sequestration and mitigation through agricultural and forestry activities. In Australia, per capita area of forested and wooded land is 28.8 ha compared to an OECD average of approximately 2 ha and a world average of 1 ha (Garnaut 2008) and our overall population density is 1-2% of the most populous countries, such as India and China. The scope of possible terrestrial land management sequestration/mitigation activities covered in this report is given in Table 1-1.

The Garnaut Climate Change Review on Australia's response to the challenge of climate change identifies significant potential for sequestration in rural lands – and a need to respond to pressures for structural change from both climate change itself and the need for mitigation. The Review listed 11 categories of sequestration/mitigation options from Australia's agriculture, forestry and other land-uses to reduce the impact of emissions on atmospheric levels of GHG and resultant climate change (see Table 22.2 in the Garnaut Review; figures reproduced in Table 1-2). These figures suggest that agriculture and forestry contributions could be substantial. It is suggested that these options, in many cases, may have relatively low costs.

Currently many of the options listed under Garnaut Table 22.2 are not covered under the articles of the Kyoto Protocol that Australia has opted to include in our national accounts for 2008-2012. Some activities sit outside the current provisions of Kyoto, such as bioenergy and biochar.

The Premier's Council on Climate Change, which provides strategic advice to the Queensland Government on priorities for action on climate change, has recognised the potential significance of sequestration for Queensland. The Council has also highlighted the current window of opportunity for government to influence the treatment of sequestration processes in national and international carbon accounting frameworks. The Queensland Government commissioned a review to refine and prioritise the sequestration/mitigation options and opportunities identified in the Garnaut Review. This report provides a qualitative analysis of the options with documented support. The aims are to guide new initiatives in sequestration investment and inform debate on the scope of sequestration options to be included in international guidelines.

The project has drawn from a broad base of national expertise within and outside of CSIRO, including Queensland Government agencies encompassing science, policy and implementation. While the review process has been held within tight time constraints, and this has limited the extent to which detailed new analysis could be conducted, it has developed a synthesis of existing information and a sound and informed assessment of each sequestration option – indicating the technical and other impediments to their use and their regional applicability across Queensland.

The project worked by establishing a consensus amongst a cross-section of scientists and land management experts. The focus was on the GHG sequestration/mitigation potential likely to be achieved through land use change in Queensland (and in a broader Australian context). For each of the options detailed in the rural land use section of the Garnaut Review (2008), a team estimated the quantity of GHG sequestration/mitigation offered over a 40 year time horizon, identifying risks and uncertainties associated with these estimates, and providing an assessment of the relative feasibility and attractiveness of the option. Regional, economic, social and institutional dimensions for each option were also considered.

The core of the report is the chapters describing in detail each of the options investigated, with Table 1-1 detailing how they correspond with the options described in Garnaut (2008). Additional options covering biochar and biodiversity plantings were also included. Chapter 1 extracts key messages from these chapters, and discusses relative magnitudes of potential benefits, the feasibility for implementation (or steps needed to facilitate implementation) and a number of other cross-cutting issues.

2 DCC (2009) National Greenhouse Gas Inventory – 2007. <http://www.ageis.greenhouse.gov.au/>

1.2 Methodology

The project aimed to refine the analysis presented in Garnaut Chapter 22, through an expert assessment of existing research. Within the timeframe and available resources, the process used was to identify a scientist experienced in the field who could lead the development of a discussion paper for each of the options in the Garnaut Review (2008), with additional analyses for biochar and biodiversity plantings, the latter including institutional, economic and social dimensions associated with land use change. Each option leader worked with a wider group of experts to set the definition and scope of the option and analyse the potential GHG sequestration or mitigation capacity for the period 2010-2050 using existing literature analysis and research experience. The initial work was described within a template which explored the background to the original numbers, the distinction between the level of biophysical potential, attainable and base levels of sequestration, the uncertainty bounds, the impediments to achieving these mitigation goals and the activities needed for more precise estimates. The effects of climate change on land use systems were not explicitly included in the analysis as much of the published work does not model them, and in addition, the effects of increasing temperature on these systems over the 40 year time horizon are not yet clear.

The options investigated are listed in Table I-1. In some instances they match the description presented by Garnaut (2008) but in others the definition and scope were more closely specified to allow tighter quantification of sequestration quantities. Where significant differences in definitional boundaries could be identified between the two studies, they are listed in Table I-1. A short title for each option is also listed; this is used to simplify presentation of results in subsequent tables.

Each option leader developed a report which included definition and scope of the option (including the GHG covered), the contributors to the synthesis and their affiliations, the key national (and international) research groups working in the area and the research activity.

The bulk of the report for each option focussed on:

- an analysis addressing the current status for the sequestration/mitigation option under discussion; the potential to improve on this; the technologies/policies/management changes that will deliver the change; the lead time to implementation; and the level of technical information available to make a valid estimate of the mitigation/sequestration opportunity;
- a discussion of uncertainty (including measures of confidence in estimates, the factors underpinning this uncertainty, and actions available to reduce the uncertainty associated with these estimates);
- risk and barriers to implementation; and
- compliance, auditing issues and status.

The authors were also asked to explore other benefits and consequences (intended or unintended) e.g. impact on biodiversity, gains in ecosystem services, potential economic benefits, business and market opportunities for rural communities and social impacts on rural communities.

For each option, a table was developed which listed the estimates for *potential*, *attainable* and *base* levels of sequestration or mitigation and the analysis including the scaling process used. These tables are produced in full in each chapter; extracts are used in this overview section to illustrate key findings.

In this study, we have assessed the *potential* estimate as the maximum biophysically possible, within the definition of the option (for example, the Carbon forestry option limits the scope to the area of land identified as suitable for forestry rather than the whole state). The potential figures in this report are equivalent in definition to those presented by Garnaut (2008).

Attainable refers to the level attainable given concerted efforts to implement the technology/management changes taking into account uncertainty of estimates and the biophysical adjustment that may be needed to make a new system work.

For some options, the additional step of estimating a *base* level was undertaken and is reported in the respective chapter. The base estimate reflects the level that might be that attained given expected political settings, institutional inertia, possible rates of adoption of technology and/or competing demands for land. This additional step has a high level of uncertainty as there is little research yet that can underpin scenario development. Consequently, the base level is not presented in the summary, as the focus of the report is to identify what are considered attainable levels of sequestration/mitigation, and it will be the strength of policy, social and economic responses that will ultimately determine the actual outcome.

The implementation of these categories (potential, attainable, base) varied between options – and the authors have described their approach in each chapter. Each option was qualitatively different so a consistent quantitative estimate of attainable levels was not applied to each option. The analysis included an assessment of biological, technical and implementation uncertainty. An economic dimension is clearly part of this assessment but was only explicitly applied in some options. For example, it was assumed that the price for carbon would largely drive land use change to carbon forestry and this option was modelled with a carbon price of

\$20/tonne, whereas the attainable level of mitigation for livestock emissions was assumed to be largely a function of the availability of appropriate technology. The report does not quantify the relative cost effectiveness of the different mitigation and sequestration opportunities.

The discussion paper for each option was circulated to a wider group of individuals with science and policy expertise. A workshop was convened on the 24th February 2009 in Brisbane, where outstanding issues were aired and resolved, and the written reports for each option were updated. In addition, the workshop identified cross-cutting issues, explored the relative feasibility of implementation and discussed economic, social and institutional aspects of each of the options and the overall approach to terrestrial sequestration in Queensland.

The review and analysis process involved 35 CSIRO scientists and a further 78 experts from other science and policy institutions around Australia. Once the discussion papers were completed, the work for each of the 11 sequestration/mitigation options was peer reviewed. The delegates to the workshop and individuals involved in the process are detailed in Appendix A.

Table 1-1: The options investigated in the review of GHG sequestration and mitigation options for Queensland - as modified from the original options in Garnaut (2008).

Option as in Garnaut (2008)	Short working title – Option description	Definitional differences between Garnaut review and this study
Land clearing (deforestation)	<i>Regrowth</i> - Carbon positive management of regrowth vegetation and remnant forest (reduce land clearing)	None identified
Enteric emissions from livestock	<i>Livestock</i> - Reduce livestock enteric emissions and structural change in industry	None identified
Removal by soil – cropped land	<i>Soil carbon</i> - Build soil carbon storage and mitigate N ₂ O emissions for cropped land (land use change from cropping to other systems not considered)	Garnaut included all cropping land (38 M ha) compared to 20 M ha for annually cropped soils used in this study
Nitrous oxide emissions from soil		
Removal by soil – high-volume grazing land	<i>Rangelands</i> - Rehabilitate overgrazed rangelands, restoring soil and vegetation C-balance (includes mulga lands). Option does not include changes in direct livestock emissions from changes in stocking rate.	Garnaut assumed all grazing land had potential to sequester carbon while this study only considered degraded land (44%) had the potential to sequester carbon. Garnaut defined mulga as all arid grazing land while this study used the defined land system classification of mulga to quantify the area.
Restoration of mulga country		
Reduction in emissions from savanna burning	<i>Savanna</i> - Mitigation of emissions from savanna burning (Kyoto-compliant gases)	Garnaut assumed 50% reduction while 90% assumed in this study (based on pilot schemes).
Removal by post-1990 forests	<i>Plantations</i> - Carbon storage in post-1990 plantations (primary goal is commercial biomass harvest)	Garnaut assumes 2 M ha of plantation while this study assumes 5.6 M ha.
Removal by pre-1990 eucalypt forests	<i>Pre-1990 Eucalypts</i> - Increase carbon banks in pre-1990 eucalypt forests	Estimate from Garnaut represents the storage expressed in different manner to this report, in that it included an additional radiative forcing effect. To allow comparison across options this form of presentation was not adopted.
Carbon forestry (plantations)	<i>Carbon forestry</i> - Change land use to carbon forestry (primary goal is carbon sequestration)	Garnaut assumes 9.1 M ha and this study assumes 147 M ha with different profit drivers.
Biofuel production	<i>Bioenergy</i> - Substitution of fossil fuels with production of biofuel and bioelectricity from renewable resources	Garnaut only included replacement of fossil fuel diesel with biodiesel.
Not quantified by Garnaut (2008)	<i>Biochar</i> - Stabilise organic carbon in <i>biochar</i> and store in soil (sugar cane biomass only)	No comparison made
Not covered by Garnaut (2008)	<i>Biodiversity</i> - Implement biodiversity plantings as carbon sink (primary goal is promotion of native biodiversity)	No comparison made

1.3 Results – an overview of potential carbon sequestration and GHG emissions mitigation

The detailed investigation of each option forms the major chapters of this report. These chapters discuss in detail the opportunities and dimensions of GHG sequestration or mitigation. This section summarises some key results from these chapters – but a more detailed discussion and reference to the relevant research is in the component chapters. It is recommended that actions arising from this report are informed by reference to these chapters.

1.3.1 The quantity of GHG savings

Table 1-2 summarises the results from the study in terms of the estimates of potential compared to the original estimates in the Garnaut Review. In addition, this table separates Queensland from Australian estimates for most options and derives values for attainable levels of sequestration and mitigation for Queensland.

Although the overall quantity was similar, there were significant differences between the potential estimates reported here for individual options and those in the Garnaut Review. In some options (Rangelands, Mulga, Pre-1990 eucalypts, Soil carbon), the estimates for potential CO₂-e sequestration/mitigation from Garnaut (2008) were greater than those reported here by a factor of 2 to 18. There were a range of other options, however, for which the estimate reported here was significantly greater than in the Garnaut Review (Savanna, Plantations, Carbon forestry). Possible reasons for these differences can be ascertained from Table 1-1.

It was not possible to estimate national figures for Bioenergy, where a national analysis was not undertaken due to time constraints and the enormous complexity of modelling, at a national level, the range of feedstocks and different pathways for biofuel/bioelectricity.

Overall figures for potential and attainable sequestration/mitigation are presented – but should be used with caution as the estimate of double counting of resources, such as land and biomass inputs, between options and varying levels of displacement or reinforcement between options is only approximate. These issues are described in more detail in Section 1.3.2. In addition, in following the Garnaut Review format, some opportunities for sequestration were not considered e.g. the full range of land use change options and their effect on soil carbon.

The additional step of calculating attainable and base sequestration/mitigation within each option helped identify many of the challenges and constraints to implementation that may arise for each option – and received general support during the process and in the workshop. For some options, base levels of sequestration were not estimated, largely due to high levels of uncertainty and an explanation is given in the relevant chapter covering these options.

While the process produced results which differed from the Garnaut analysis in some instances, it reinforced the potential importance of terrestrial sequestration and mitigation. Importantly, we have identified sequestration potential with feasibility filters i.e. a conscious attempt, albeit subjective, to differentiate attainable levels of sequestration/mitigation from the biophysical potential.

A definitive specification of an overall figure for terrestrial sequestration is complicated because many options overlap – an investment or development of one option will limit the potential for development of others. These cross-cutting issues are identified and discussed in more detail below.

Overall the process has reinforced the clear potential for better and altered land management to be an important part of the carbon management policy for Queensland. In achieving this, there will need to be change in policy and economic settings. Some change will be possible within the state, some will require adjustment to national settings and some are dependent on international developments, especially in the carbon accounting framework for the post-Kyoto climate agreement.

The following sections discuss the results in terms of overlaps in options, relative barriers to implementation, the emerging policy context of each option, and how terrestrial carbon management might apply in the different regions of Queensland.

1.3.2 Overlaps and complements

During the project, it was clear that a formal investigation of the links and trade-offs between sequestration options is needed – various forms of linear programming or stocks and flows analysis were suggested. The timeframe for producing this report did not allow more complex analysis and the report does not quantify the relative cost effectiveness of the different mitigation and sequestration opportunities; this remains a need. As an interim measure, through the workshop and in subsequent analysis, the degree of overlap or synergy between options was estimated based on clear overlap and competition for land resources. The report identifies connections between options and explores the degree of displacement or synergy likely to occur as emphasis increases in capturing mitigation or sequestration benefits. This does not indicate a robust quantitative assessment but can be viewed as the starting point for a more substantial investigation.

Table 1-2: Annual GHG sequestration/mitigation (Mt CO₂-e) both nationally and within Queensland over a 40 year time horizon (2010-2050) using estimates from Garnaut (2008) and independent analysis (shaded options are subset of another option or compete for resources with another option and are not included in total figures).

Option	Garnaut (2008)	Estimates from this study (Mt CO ₂ -e/yr)		
		National Potential	National Potential	Queensland Potential Attainable
AGRICULTURE				
Rehabilitate overgrazed <i>rangelands</i> , restoring soil and vegetation C-balance	286	100*	35	18
Rehabilitate mulga lands, restoring soil and vegetation C-balance (subset of <i>rangelands</i>)	250	20*	4	2
Mitigation of emissions from <i>savanna</i> burning (Kyoto-compliant gases)***	5	13*	2	1
Build soil carbon storage and mitigate N ₂ O emissions for cropped land (land use change not considered)	68	25*	4	0.4
Reduce livestock enteric emissions and structural change in industry***	16	26	11	7
GHG sequestration/mitigation for Agriculture (accounting for overlap of options)		164	52	26
FORESTRY				
Change land use to <i>carbon forestry</i> (primary goal is carbon sequestration)	143	750*	153	77
Biodiversity - Implement <i>biodiversity plantings</i> as carbon sink (primary goal is promotion of native biodiversity; subset of <i>carbon forestry</i>)	<i>Not estimated</i>	350	56	28
Carbon storage in post-1990 <i>plantations</i> (primary goal is commercial biomass harvest; competes for resources with <i>carbon forestry</i>)	50	400	97	2
Increase carbon banks in <i>pre-1990 eucalypt</i> forests	136	47*	21	21**
Carbon positive management of <i>regrowth</i> vegetation and remnant forest (reduce land clearing)	63	56	38	7
GHG sequestration/mitigation for Forestry (accounting for overlap of options)		853	212	105
BIOENERGY***				
Substitution of fossil fuels with biofuel/bioelectricity from 1 st gen. biomass resources	44 (mix of 1 st , 2 nd gen sources)	Not estimated	5	1
Substitution of fossil fuels with biofuel/bioelectricity from 2 nd gen. biomass resources		Not estimated	24	8
Stabilise organic carbon in biochar and store in soil (sugar cane biomass only; competes for resources with 2 nd gen. biomass)	<i>Not estimated</i>	9	8	4
GHG sequestration/mitigation for Bioenergy (accounting for overlap of options)		Not estimated	29	9
Total GHG sequestration/mitigation for Queensland (accounting for overlap of options)			293	140

* Where estimates are significantly different between the Garnaut Review and this study the reason is often definitional and related to the area of land, however in some instances the estimated carbon sequestration rates also varied.

**The potential and attainable are equal in this instance as the forest is an existing resource.

***These options will be continuous in their sequestration/mitigation while other options will saturate over time.

Table 1-3: Identification of overall GHG sequestration/mitigation outcomes where competing or complementary options are pursued – including a qualitative description of the interaction and quantum of the overlap.

Option	Nature of Double Counting Across Options	Qualitative Description	Qualitative Assessment of Quantum of Overlap
Rangelands and Mulga	Complementary ³	Mulga is a direct subset of the rangelands and is included in overall figures for rangelands	High
Rangelands and Regrowth	Complementary	The rangelands woody plant regeneration includes preservation of existing vegetation	Low
Rangelands and Biodiversity	Complementary	Some of the potential for revegetation under the rangelands option would be covered by biodiversity plantings in lower rainfall regions	Low
Rangelands and Savanna	Complementary	Savanna is a direct subset of the rangelands and the carbon sequestration potential (not fire CH ₄ and N ₂ O emissions) would be included in the rangelands option	Low
Mulga lands and Regrowth	Complementary	The mulga lands tree and shrub regeneration includes preservation of existing vegetation	Low
Mulga lands and Biodiversity	Complementary	Some of the potential for revegetation under the mulga option would be covered by biodiversity plantings in lower rainfall regions	Low
Biodiversity and Carbon forestry	Complementary	Biodiversity planting is a direct subset of carbon forestry and is included in overall figures for carbon forestry	High
Carbon forestry and Plantation	Competitive ⁴	Plantation plantings (for commercial harvest) are on high-value land which would overlap almost 100% with some of the area identified as suitable for carbon planting	High
Bioenergy and Plantation	Competitive	Feedstock for bioenergy assumed to be grown on some of the same area planted to commercial plantations	Low
Bioenergy and Carbon forestry	Competitive	Feedstock for bioenergy assumed to be grown on some of the same area planted to carbon forestry	Low
Bioenergy and Soil carbon	Competitive	Feedstock for bioenergy assumed to be grown on some of the same area as crops, and competition for crop stubble.	Low
Bioenergy and Biochar	Competitive	Direct competition between Bioenergy and Biochar for sugar cane biomass	High

³ Complementary means that the same positive outcome is achieved (in terms of GHG sequestration) from the overlap between the two Options. For example, carbon biosequestered in the Rangelands and the Mulga lands ends up with carbon in the same place giving the same benefit.

⁴ Competitive means that the GHG sequestration for one option is negatively affected by the use of the same resources in another option. For example, carbon sequestration in Carbon forestry is foregone if some of the land is used to grow feedstock for Bioenergy.

1.3.3 Relative barriers to implementation

In the discussion of the individual options, each team discussed the immediate and emerging barriers to implementation of the GHG sequestration or mitigation. This section develops a meta-analysis of these barriers – the detail remains in the individual chapters. For this exercise, the five factors most likely to contribute to the delivery of a final benefit were assessed.

Using the discussion papers and input from the workshop discussions, the project team and option leaders ranked the options from 1 (bad) to 5 (good) on a qualitative basis; a consensus value was agreed for each option. Equal weight was given to the factors to estimate an overall rating for each option and these were checked against the “expert” opinion of the option leaders.

The factors that were assessed were:

- **Maturity of science and technology:** Are technical solutions currently available to enable the option to be implemented? Biochar was given the lowest rating and Plantations and Regrowth the highest.
- **Measurement feasibility:** Are there reliable and cost effective means of measuring GHG sequestration/mitigation? Pre-1990 Eucalypts, Rangelands, Mulga and Biodiversity were rated at the lower end with Regrowth and Plantations highest.
- **Ease of implementation:** Are there existing models for implementation? Biochar, Pre-1990 Eucalypts and Rangelands were assigned the lower ratings and Plantations the highest.
- **The net benefit of co-effects:** Are there well defined co-benefits or trade-offs associated with the option? Mulga, Pre-1990 Eucalypts, Plantations and Biofuels 1st gen were rated lowest; Biodiversity and Savanna the highest.
- **System stability/certainty into which the options would be applied:** How variable are the natural systems into which the option will be applied? How well are these systems defined and understood? Rangelands had the lowest rating and Plantations and Carbon forestry the highest.

The decision on factors used and the relative ratings were somewhat arbitrary and were developed based on the analyses of the individual options. More sophisticated and structured methods could be applied to this area of analysis. However, in the time frame for delivery of the report this simplified system gives some indication of the relative “merit” of each option considered against the potential GHG benefit delivered. To emphasise the qualitative nature of this assessment, results are presented with variable shading rather than numerically, with darker shades indicating a more favourable rating (Table I-4).

1.3.4 Emerging policy context

International and national policy frameworks will influence implementation of the various sequestration/mitigation options. The Australian Government has demonstrated a clear desire for only Kyoto Protocol compliant sinks and sources of GHG to be recognised in the proposed Carbon Pollution Reductions Scheme (CPRS). The Australian Government has also drafted a National Carbon Offset Standard to provide greater confidence for consumers who wish to go beyond the mandatory requirements of the CPRS, by purchasing carbon offsets on the voluntary market.⁵ Therefore, there is considerable overlap, but not total consistency, in how each sequestration/mitigation option is treated under the Kyoto Protocol, CPRS and the Offset Standard. The current status of each option under international (Kyoto) and national policy (proposed CPRS and proposed voluntary market standard) is detailed in Table I-5.

We will discuss Kyoto first. Although the analysis undertaken in this report shows that all Options examined have the potential for GHG sequestration/mitigation, some can be implemented immediately as Kyoto-compliant while others are yet to be negotiated as part of a global accounting framework. Some may never be included.

To inform the discussion in this section of the report, the following background on the Articles that set out operation of the Kyoto Protocol is useful.

⁵ Comments closed on the public discussion paper in February 2009.

Table 1-4: Qualitative assessment of the “merit” of each option for factors other than the quantity of GHG benefit - maturity of technology, ease of measurement and implementation, impact of co-effects and system certainty. Intensity of shading indicates the relative rating; more intense shading indicates a more favourable rating.

Option	Maturity of Science & Technology	Measurement Feasibility	Ease of Implementation	Net Benefit of Co-effects	System Stability/Certainty	Overall Rating	Nature of Co-effects, incl. payment for CO ₂ -e
Rangelands							Plus: Biodiversity, eco-system stability, reduced erosion, alternate income. Minus: Loss of regional jobs (livestock related).
Mulga							Plus: Biodiversity, eco-system stability, reduced erosion, alternate income. Minus: Loss of regional jobs (livestock related).
Regrowth							Plus: Biodiversity, eco-system stability, alternate income. Minus: Loss of production, capital value of land.
Biodiversity							Plus: Biodiversity, eco-system stability, reduced erosion, alternate income, regional jobs. Minus: Displaced land use (food, water). ⁶
Savanna							Plus: Biodiversity, eco-system stability, reduced erosion, regional jobs, cultural heritage.
Pre-1990 Eucalypts							Plus: Tourism, biodiversity. Minus: Loss of regional jobs (timber related).
Plantations							Plus: Alternate income. Minus: May reduce biodiversity, displaced land use (food, water).
Carbon forestry							Plus: Alternate income, neutral for biodiversity. Minus: Displaced land use (food, water). ⁶
Soil carbon							Plus: Soil protection, production efficiency, alternate income.
Livestock							Plus: Biodiversity, eco-system stability, reduced erosion. Minus: Loss of regional livestock jobs, leakage to other regions.
Biofuels – 1 st gen							Plus: Energy security, regional jobs, waste management. Minus: Loss of biodiversity, displaced land use (food, water).
Bioenergy – 2 nd gen							Plus: Energy security, regional jobs, waste management. Minus: Loss of biodiversity, displaced land use (food, water).
Biochar							Plus: Energy security, regional jobs, waste management, soil amelioration. Minus: Loss of biodiversity, displaced land use (food, water).

⁶ Change in land use can cause unfavourable impacts on food production and availability of water for downstream use.

Article 3.1 covers all anthropogenic carbon dioxide equivalent emissions of the greenhouse gases listed in Kyoto Annex A (carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride). All signatories with an emissions target under Kyoto include these emissions in their Kyoto accounts (called the National GHG Inventory in Australia).

Article 3.3 covers net changes in greenhouse gas emissions by sources and removals by sinks resulting from direct human-induced land-use change and forestry activities, limited to afforestation, reforestation and deforestation since 1990. All signatories with an emissions target under Kyoto include these GHG sources and removals by sinks in their Kyoto accounts.

Article 3.4 refers to data each country could elect to use to establish its level of carbon stocks in 1990, to enable an estimate to be made of its changes in carbon stocks in subsequent years. Article 3.4 covers land use that is not afforestation, reforestation or deforestation since 1990. This includes GHG sources and removals by sinks associated with forest management, cropland management, grazing land management and revegetation. Australia has chosen not to include any emissions or removals from any Article 3.4 activities in its national Kyoto accounts for 2008-2012. This is primarily because if a country elects an activity, it must include all carbon movement from activities on the land. Australia has high risks of drought and bushfires which can release large quantities of GHGs.

We have loosely rated each option into four categories to give some indication of possibilities going forward from 2012, in terms of international climate treaty negotiations. Some options, such as Regrowth and Biochar, appear under two categories reflecting the fact that some of the sequestration potential is recognised under current Kyoto rules while other parts of the potential are not.

Category 1: Options covered by Kyoto Protocol which Australia has elected to include in 2008-2012 accounts

- The options that are currently covered by Kyoto are those that use forests to sequester carbon on "Kyoto land" (land that was clear of forest in 1990 and is converted to forest as a result of direct human intervention) and those that include reduced clearing of pre-1990 forests. These options are Regrowth (reduced clearing of regrowth that existed on 1 Jan 1990), Plantation, Carbon forestry and Biodiversity (if the vegetation meets the definition of 'forest' under Kyoto rules⁷).
- Carbon sequestration in regrowth on land that was cleared post-1990 is also included in Australia's Kyoto accounts for net deforestation.
- Also in this category are those Options that mitigate methane and N₂O emissions from anthropogenic activities (Livestock, the N₂O component of Soil carbon, Kyoto-compliant gases for Savanna).
- These activities are covered by Article 3.1 and 3.3 and count towards Australia's Kyoto target and any additional investment will have direct effect on Australia's Kyoto GHG accounts.

Category 2: Options covered by the Kyoto Protocol which Australia has not elected to include in 2008-2012 accounts

- For a number of the options investigated, the Kyoto framework exists to account for GHG sequestration, but Australia has elected not to include these Article 3.4 activities in its Kyoto accounts for 2008-12. The options that clearly fit into this category are Rangelands, Mulga, Soil carbon (carbon storage) and Savanna (carbon storage).
- Additional options may be covered by Article 3.4 activities, but with less certainty, as detailed consideration is yet to be given as to what may or may not be covered by the Article 3.4 activities. Pre-1990 Eucalypts would clearly fit under forest management if managed for wood products but forest in national parks may or may not fit the "managed" criteria to qualify for inclusion. Regrowth on land cleared pre-1990 would not qualify under the revegetation activity unless there is evidence that it is human induced; regrowth could qualify if it is the outcome of change in grazing management. Potentially Biochar could also be covered by Article 3.4 if it is added to agricultural soil, an issue yet to be resolved as biochar could also potentially be used for other purposes while still sequestering carbon.

We note that there may be a push for post-Kyoto carbon accounting rules under Article 3.4 to treat man-made sources of emissions separately to those caused by "major natural disturbances" which could influence Australia's deliberations on whether to include these activities post 2012.

Category 3: Options not covered by the Kyoto Protocol which might be considered in post-Kyoto negotiations

- Only one option would potentially fit this category and that is Biochar. An alternative approach could be taken to claiming credit for carbon captured and stored in biochar: rather than focusing on the increase in soil carbon stock, credit could be based on the avoided emissions due to stabilizing organic matter.

Category 4: Options for which Kyoto is not directly relevant

- These options include Bioenergy and the co-generation of bioenergy in the Biochar Option. However, these options do have the potential to displace fossil fuel use – emissions from which are included in our national accounts.

⁷ Australia's definition of a forest under the Kyoto Protocol is a minimum area of 0.2ha, 20% crown cover and tree height of 2m.

The interrelationship between Kyoto and CPRS compliance is such that the proposed CPRS will only cover sources and sinks that are included in Australia's Kyoto accounts. Therefore, the CPRS policy context largely follows the discussion for Kyoto Protocol categories.

All afforestation and reforestation (covered by agreed Kyoto accounts for 2008-2012) will be included, on a voluntary basis, from the commencement of the CPRS in 2011. The decision to include agriculture as a covered sector in the CPRS will be made in 2013, and if agreed, will commence in 2015. If the decision is not to include agriculture, mitigation strategies (as alternate to being a covered sector in CPRS) are proposed in the CPRS White Paper but no date for possible introduction is given.

In general, CPRS will only cover sources and sinks that are included in Australia's Kyoto accounts. The criteria for eligible offsets proposed under the National Carbon Offset Standard broadly follow those for generating carbon pollution permits under CPRS.

The carbon policy status of each option is detailed in Table 1-5.

Table 1-5: Status of each GHG sequestration/mitigation option under Kyoto Protocol, proposed Carbon Pollution Reduction Scheme and National Carbon Offset Standard.

Option	Kyoto Status of GHG Sequestration/Mitigation	Proposed CPRS and proposed National Carbon Offset Standard status of GHG sequestration/mitigation
<p>Rangelands and Mulga - Rehabilitate overgrazed rangelands, restoring soil and vegetation C-balance (including mulga lands).</p> <p>Option does not include changes in direct livestock emissions from changes in stocking rate.</p>	<p>Covered by Article 3.4 – grazing management, which Australia has not elected to include in its Kyoto accounts for 2008-12.</p>	<p>Not included in CPRS or offset standard.</p>
<p>Regrowth - Carbon positive management of regrowth vegetation and remnant forest (reduce land clearing)*</p>	<p>Clearing of regrowth is deforestation under Kyoto Article 3.3. This applies to regrowth that occurred pre-1990 and post-1990. Therefore, any reduction in land clearing counts towards Australia's Kyoto accounts.</p> <p>Pre-1990 regrowth that is not cleared is not eligible under Kyoto Article 3.4 (forest management) due to Australia not selecting Article 3.4.</p> <p>Regrowth on land that had forest on it at 1 Jan 1990 is counted towards net deforestation for Kyoto accounts.</p> <p>If regrowth occurs on land clear of forest vegetation on 1 Jan 1990 it is not included as a sequestration event unless there is evidence that it is the result of direct human activity.</p>	<p>Clearing of regrowth (deforestation) is not included in CPRS. Land clearing is regulated by state legislation and nationally agreed frameworks.</p> <p>Reforestation is included in CPRS or as a potential offset for the voluntary market if there is evidence that it is the result of direct human activity.</p>
<p>Biodiversity - Implement biodiversity plantings as carbon sinks</p>	<p>Eligible under Article 3.3 (as afforestation or reforestation), providing it meets current Kyoto requirements of canopy cover of >20% and patches >0.2 ha, and >2m high.</p> <p>If these requirements are not met biodiversity plantings could be covered by revegetation under Article 3.4 in a post-Kyoto agreement.</p>	<p>Biodiversity plantings can be included in CPRS on voluntary basis from 2011 but must be Kyoto-compliant. Forests established on land cleared of forest since 1 Jan 1990 would not be eligible for CPRS.</p> <p>Australian carbon pollution permits (under CPRS) could also be eligible offset units to sell on the voluntary market if they meet standards set in the proposed National Carbon Offset Standard.</p>

Option	Kyoto Status of GHG Sequestration/Mitigation	Proposed CPRS and proposed National Carbon Offset Standard status of GHG sequestration/mitigation
Savanna - Mitigation of emissions from savanna burning (Kyoto compliant gases)	Covered under Article 3.1.	Potential for offsets to be included in CPRS and National Carbon Offset Standard is under investigation.
Savanna - Increase sequestration of carbon from reduction in savanna burning	Covered by Article 3.4 – grazing land management, which Australia has not elected to include in its Kyoto accounts for 2008-12.	Although not proposed for inclusion in CPRS as offset from commencement of Scheme – Commonwealth Government has committed to consult with Indigenous Australians on potential as offset under the scheme. Could be an accredited offset under the proposed National Carbon Offset Standard.
Pre-1990 Eucalypts - Increase balance of carbon banks in pre-1990 eucalypt forests	Managed forests covered by Article 3.4 (forest management) but unmanaged forests are not included. Not eligible under Kyoto due to non-selection of Article 3.4.	Not included within the CPRS or covered in the proposed National Carbon Offset Standard.
Plantation - Maintain and expand carbon storage in post-1990 plantations (primary goal is commercial biomass harvest)	Eligible under Article 3.3 (as afforestation or reforestation), providing it meets current Kyoto requirements of canopy cover of >20% and patches >0.2 ha, and >2m high.	All plantings can be included in CPRS on voluntary basis from 2011 but must be Kyoto compliant. However, scheme plantings designed for single harvest are unlikely to be included in CPRS (as emissions from harvest may exceed residual carbon sequestration). Forests established on land cleared of native forest since 1 Jan 1990 would not be eligible for CPRS. Australian carbon pollution permits (under CPRS) could be eligible offset units under the proposed National Carbon Offset Standard.
Carbon forestry - Change land use to carbon plantings (primary goal is carbon sequestration)	Eligible under Article 3.3 (as afforestation or reforestation), providing it meets current Kyoto requirements of canopy cover of >20% and patches >0.2 ha, and >2m high. If these requirements are not met carbon forestry plantings could be covered by revegetation under Article 3.4.	All plantings can be included in CPRS on voluntary basis from 2011 but must be Kyoto compliant. Forests established on land cleared of native forest since 1 Jan 1990 (classified as deforestation under Kyoto) would not be eligible for CPRS. Australian carbon pollution permits (under CPRS) could also be eligible offset units to sell on the voluntary market if it meets standards set in the proposed National Carbon Offset Standard.
Soil carbon - Build soil carbon storage and mitigate N ₂ O emissions for agricultural land	Emissions covered under Article 3.1 (N ₂ O). Soil carbon covered by Article 3.4 – agricultural soils, which Australia has not elected to include in its Kyoto accounts for 2008-12.	Decision about whether to include N ₂ O emissions in CPRS from 2015 will be made in 2013. Mitigation strategies (as alternate to being a covered sector in CPRS) are proposed in the CPRS White Paper but no date for possible introduction is given. Carbon sequestration in soil would not currently meet proposed certification requirements for proposed National Carbon Offset Standard (additional, permanent, measurable, transparent and auditable).

Option	Kyoto Status of GHG Sequestration/Mitigation	Proposed CPRS and proposed National Carbon Offset Standard status of GHG sequestration/mitigation
<p>Livestock - Reduce enteric emissions from livestock industries - individual animal emissions and industry structural changes.</p> <p>Option does not include changes in landscape C-balance from changes in stocking rates.</p>	<p>Article 3.1 covers methane emissions from livestock</p>	<p>Decision to include agriculture as covered sector in the CPRS will be made in 2013, for commencement in 2015. CPRS will only cover sources and sinks that are included in our Kyoto accounts (i.e. currently methane).</p> <p>Mitigation strategies (as alternate to being a covered sector in CPRS) are proposed in the CPRS White Paper but no date for possible introduction is given.</p>
<p>Bioenergy - Substitution of fossil fuels with production of biofuel and bioelectricity from renewable resources</p>	<p>Mitigation for fossil energy sector (covered by Article 3.1)</p>	<p>Under CPRS, biofuels/bioelectricity can be considered under the Renewable Energy Target to be used to drive technology uptake until carbon market is mature (2020-2030). The use of biofuels/bioelectricity is not a carbon offset but a means of mitigating carbon footprint for a business.</p>
<p>Biochar - Stabilise organic carbon in biochar and store in soil</p>	<p>Possibly Article 3.4 if considered as a component of soil carbon in agricultural soil, which Australia has not elected to include in its Kyoto accounts for 2008-12.</p> <p>Carbon storage from biochar is on the agenda for consideration in negotiations of next commitment period.</p> <p>Co-generation of bioenergy gives mitigation for fossil energy sector (covered by Article 3.1)</p>	<p>Biochar will not generate permit credits in CPRS unless recognised in post-Kyoto treaty. With additional research, biochar (but not biofuel/bioelectricity from pyrolysis) may be an accredited offset in the proposed National Carbon Offset Standard if it meets the principles of being additional, permanent, measurable, transparent and auditable.</p>

* During the Kyoto negotiations, Australia successfully sought to include the unusually high 1990 land clearing emissions (approximately 130 Mt CO₂-e) in the determination of baseline emissions. The 1990 clearing rate reflected economic and weather conditions for regions with the potential for land clearing during 1990, plus the imminent introduction of legislation to control clearing (from a land use/vegetation management policy perspective rather than climate change). When the Kyoto Protocol was negotiated in 1997, there had already been a big decrease in land clearing which has continued as state governments have tightened conditions under which permits for clearing are issued.

1.3.5 Regions and terrestrial carbon management

The distribution of terrestrial carbon management options varies substantially across the state – so that regions will vary in the emphasis on specific options and the benefits likely to be obtained. Within regions, a substantial challenge will be the spatial mix to produce the optimal outcomes for carbon capture/mitigation, food production, environmental protection and biodiversity levels.

The fifteen Natural Resource Management (NRM) bodies have been grouped into five broader groups to assist discussion of the local priorities (Figure 1-1). Mitigation of livestock emissions will be important in all regions and a strong priority through central Queensland.

South-east Queensland (SEQ NRM Body): The main emphasis in this region will be on carbon forestry with plantations, some development of bioenergy production, application of biochar and some soil carbon build up in grazing lands.

Coastal Queensland: (includes Burnett Mary, Mackay-Whitsunday and Terrain NRM regions and coastal areas within the Fitzroy and Burdekin regions). This region has most options available but the main gains are likely to come from developments in bioenergy and the production and use of biochar; changes to the management of regrowth and carbon forestry and harvested plantations.

Central Queensland: (includes Condamine Alliance, eastern sections of QMDB and non-coastal areas of the Fitzroy and Burdekin regions). As well as the strong emphasis on livestock emission abatement, this region has the broadest range of options available. There will particular emphasis on the management of regrowth for both carbon and biodiversity outcomes, the restoration of soil carbon in grazing and cropping lands and carbon plantations.

North Queensland: (includes Southern Gulf, Northern Gulf and Cape York regions). Carbon management options in this region are dominated by the restoration of soil carbon in grazing lands and the management of savanna burning. Livestock management is interconnected with these options.

South-west Queensland: (includes South-West NRM and Desert Channels regions). This region has a relatively narrow range of options and the concentration will be on the benefits arising from rehabilitating grazing lands including the mulga lands, and limited opportunities for biodiversity plantings.

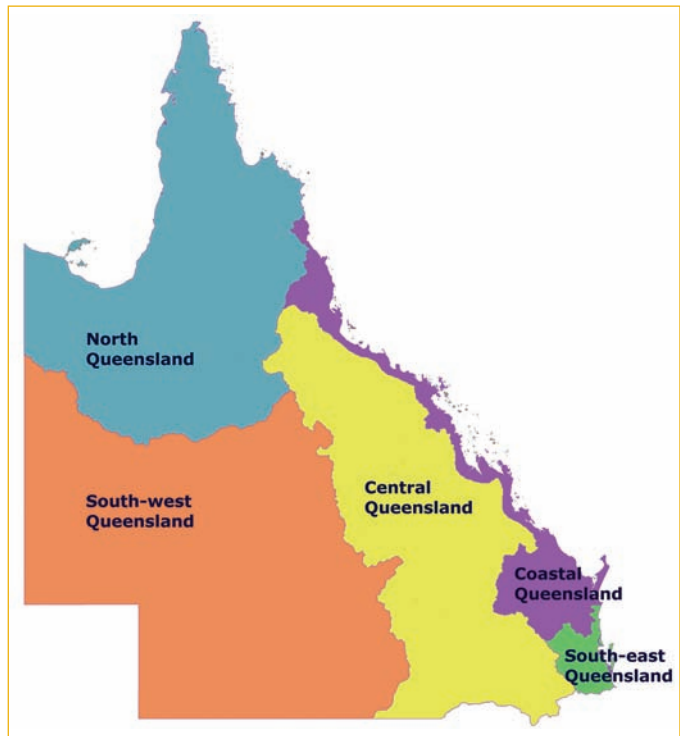


Figure 1-1: Grouping of regional Natural Resource Management areas in Queensland.

1.4 Priorities and initiatives

Some clear options which have emerged from the analysis are explored in this section. This is not an exhaustive analysis, rather an initial scoping of the process needed to pursue these options.

The most favourable options currently are those that deliver a high quantity of attainable GHG sequestration or mitigation with a high “rating” for other factors that will drive the final storage outcome (Table 1-4). To illustrate this, Figure 1-2 maps the attainable quantity of GHG benefit against a rating of the other factors in Section 1.3.3, with “traffic light” colours giving an indication of the relative difficulty in achieving these levels of GHG abatement for each Option. The best positioned Option is Carbon forestry, with Regrowth, Plantations and Savanna showing similar “ratings” but decreasing quantity of GHG sequestration. Options with relatively low CO₂-e quantities, such as Savanna, are worth investment because the favourable rating indicates that this option should reliably deliver GHG savings.

Some of the lower quantity options such as Livestock merit further R&D investment to assess feasibility and overcome science barriers, particularly given the importance of the beef industry in Queensland. Investment in Biofuels 1st gen has a relatively small carbon offset value. It is widely accepted in Australia that the future of any significant scale-up in biofuel production must be in second generation technologies, due to the issues that have arisen internationally with large-scale diversion of grain, canola and palm oil to biofuels.

Sequestration of carbon in soils under cropping, delivers the lowest GHG abatement of all the options considered and with only moderate ease of implementation. Soil carbon changes associated with land use change (crop to pasture, pasture to trees) were not included in this report. Although major additional soil carbon storage could theoretically be achieved by land use change, the potential rates of storage and areas of land are difficult to define, and modelling optimal allocation of land resources to carbon storage or food production is yet to be undertaken.

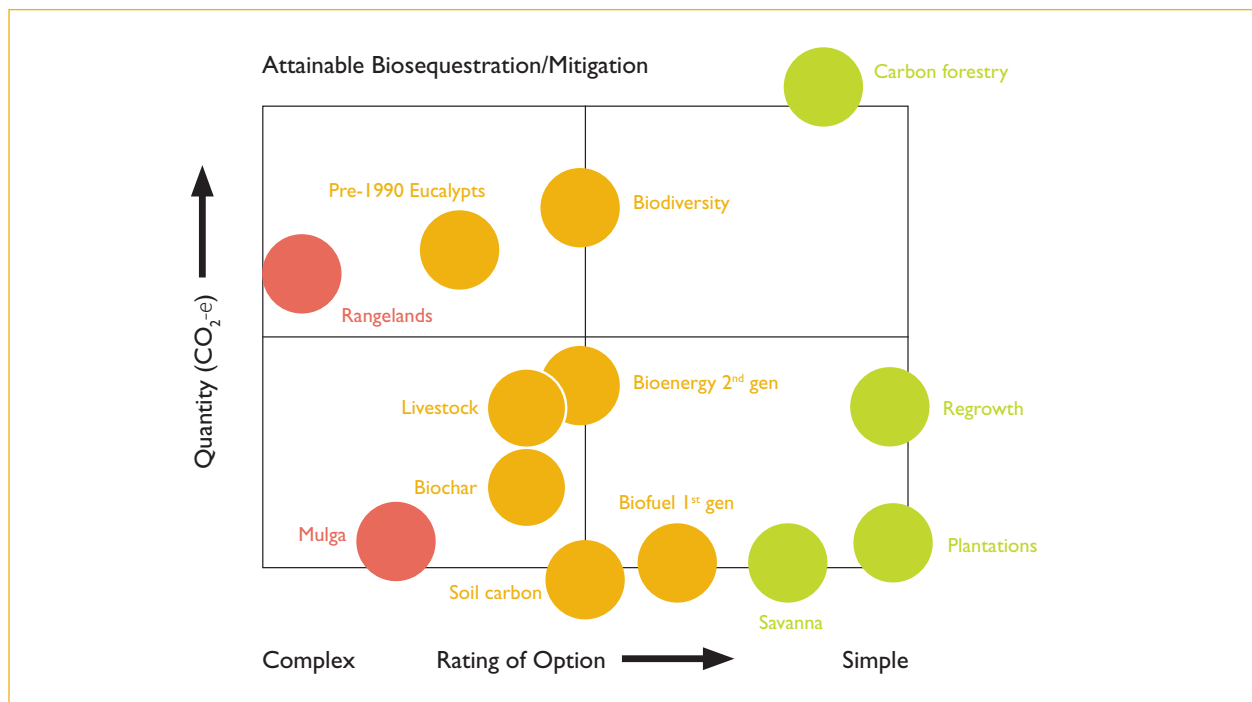


Figure 1-2: Qualitative assessment of the attainable GHG biosequestered/mitigated for each option (for Queensland) plotted against the overall rating for complexity of implementation attributes (maturity of technology, ease of measurement and implementation, impact of co-effects and system certainty) with balls in red being the most difficult and green the least difficult to implement.

Biodiversity and Pre-1990 eucalypts have the potential to deliver GHG savings of greater magnitude but still have considerable barriers to overcome in terms of the maturity of the science and certainty in implementation. Bioenergy 2nd gen and Biochar also require more investment before they can be effectively implemented, but these options have added value - in that they can continue to offset the burning of fossil fuels indefinitely, and in the case of biochar, store carbon in a stable form in the soil. Enabling production of biofuels also has additional importance, over and above its abatement potential, as there are few other options for replacement of liquid fossil fuels.

The problematic options are those with low GHG savings and low rating, such as Mulga. This suggests that a focus on the Mulga lands is the least likely to deliver significant benefit to Queensland in terms of GHG sequestration. Scaling up to the whole Rangelands gives higher potential quantity for GHG sequestration, but it has the lowest overall rating for ability to deliver outcomes. These two options may still be worth pursuing, but higher relative investment in assessment, monitoring and modelling will be required. Based on these general trends it may be more profitable to invest in other options first.

Such investment could still encompass activities in the rangelands, particularly in the area of biodiversity plantings, where the outcome in terms of carbon storage is likely to be more certain. In using this report it will be important that the relatively low merit of using the rangelands for sequestration does not interrupt critical signals that the rangelands need to be better managed for biodiversity and eco-system stability.

The attainable quantities of GHG sequestration/mitigation for each option are presented graphically in Figure 1-3; options which directly overlap are combined. These figures reflect the “experts” considered opinion on how much of the potential quantity might be biosequestered/mitigated in practice, taking into account current biophysical and production systems constraints. It should be noted that this is a subjective assessment (the assumptions used are detailed in each chapter) and would benefit from further study. It should also be noted that this reflects the current situation, especially in terms of maturity of science and technology, and measurement feasibility. Figure 1-3 shows the quantity of GHG savings delivered by each Option with “traffic light” colours giving an indication of the relative difficulty in achieving these outcomes for each Option.

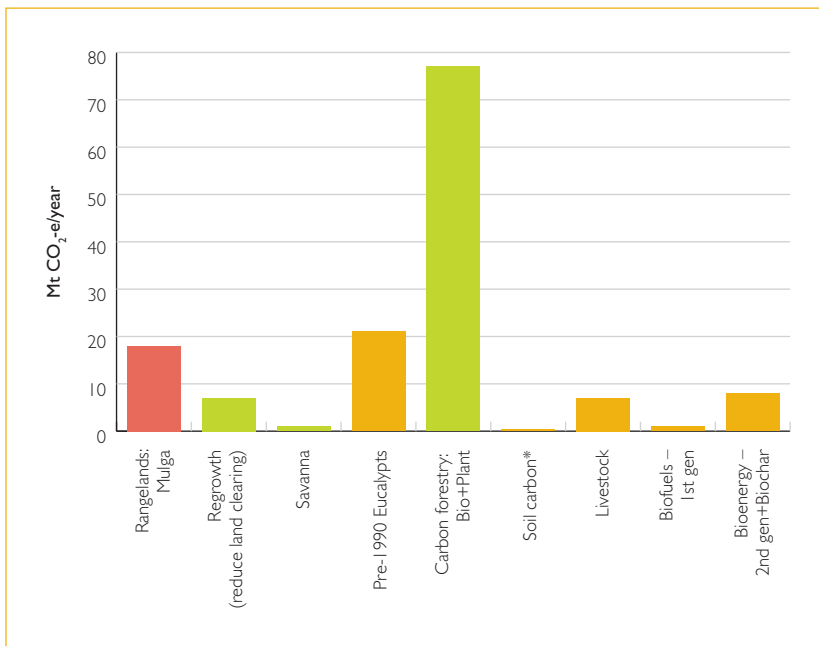


Figure 1-3: Attainable quantity of GHG sequestration/mitigation delivered for Queensland with options combined where there are direct overlaps, bars in red being the most difficult and green the least difficult to implement. *The soil carbon figure is based on residue and fertiliser management in cropping systems and does not include soil carbon change associated with changes from cropping to pastures or trees.

1.5 Implications for rural land use

The assessments in this report have been guided by expert assessment drawing upon existing information with limited re-analysis. Evidence is presented on the derivation of estimates and the factors generating uncertainty. In many cases uncertainty is high, and data sparse. While numbers are provided, they are best suited to gauging order of magnitudes of sequestration options, such that the potential opportunity and the regional focus can be compared against the technical, social and environmental impediments to application. The report has suggested that overall the potential is similar to that indicated in the Garnaut Review, but estimates for individual options vary, some being significantly lower while others are significantly higher.

The broad thrust of the Garnaut Review is supported – within Queensland an overall technical potential of 293Mt CO₂-e/yr was estimated with perhaps 140Mt of this potential being attainable with concerted efforts in technical and management changes, policy adjustment and shifts in current land management priorities. It must be recognised that these estimates contain a combination of biological, technical and implementation uncertainty.

Queensland emissions in 2007 were 182 Mt – so the attainable estimate of 140 Mt CO₂-e/yr, indicates that terrestrial GHG management could play a key role in emissions abatement over the next 40-50 years. A complete set of national estimates was not undertaken but where they were available the results suggest a similar outcome would be achieved.

The largest quantities of abatement are associated with options that cover forestry activities such as carbon forestry (including biodiversity plantings), commercial forest plantations, and reduced land clearing/managed regeneration. Estimates are that these options may account for approximately 105 Mt CO₂-e/yr, and importantly have relatively low barriers to implementation. Across many of the other studied options, it is clear that enabling technology and appropriate policy incentives could lead to a significant reduction in emissions or increased carbon sequestration. Changes in agricultural practices to build carbon reserves in agricultural and rangelands systems could yield 26 Mt CO₂-e/yr while substitution of fossil fuels with renewable bioenergy could reduce emissions by 9 Mt CO₂-e/yr.

Numbers contained in the report's tables are not additive: the total sequestration opportunity for Queensland can not be inferred by tallying all the numbers provided. The presence of overlaps and synergies requires a planning approach which optimises land and feedstocks to the various carbon-sinks according to the key local and state issues e.g. – regional needs and priorities, potential for substitution of end-products. Co-benefits may be highly influential, particularly if co-payments for such ancillary benefits provide additional financial means for producing carbon outcomes.

After the overlap analysis, we estimate that the total potential for abatement might be in the order of 64% of a simple addition.

Thus the overall biophysical potential for Queensland would be in the order of 293 Mt CO₂-e/yr. Using similar methods to account for the overlap in attainable sequestration/mitigation gives a figure in the order of 140 CO₂-e/yr. Even recognising that the attainable estimates have a margin of error; with estimated emissions for Queensland of 182Mt CO₂-e/yr in 2007, terrestrial GHG management potentially has an important role to play over the next 40 years, within an overall program of GHG abatement.

A number of important provisos need to be recognised:

- Most sequestration options will reach saturation at some point in time with a likely time horizon of 40-50 years. Bioenergy and Biochar will continue to deliver GHG savings indefinitely if based on a renewable biomass source.
- Sequestration has large natural uncertainties compared to achieving similar abatement through reduction in burning of fossil fuels.
- Broad scale application of tree plantings into new regions may require an understanding of new systems and species and has logistical issues in terms of how quickly it could be implemented.
- Broad scale land use change will have impacts on existing agricultural enterprises, eco-systems and regional development. These may not all be favourable but more importantly, are at the moment not well understood.

Figure 1-2 demonstrates the dominating effect that a strong carbon price could have on converting land use over to carbon forestry. The area assumed to be planted to carbon forestry was 8.5 M ha or 4.6% of the area of Queensland. Although this figure sounds small there are overlaps with agricultural and grazing land, which means there is a real and immediate imperative for the investigation of the impact of proposed land use change on food production at a national level and eco-system services and socio-economic health at regional or catchment level. The economic assumptions used for the Carbon forestry option would have excluded high value horticultural land but not agricultural land used for grazing and broad-acre cropping.

Some other options, particularly restoration of rangeland and mulga ecosystems and to a lesser extent the option involving management of native forests are confounded by a lack of quantitative data, huge natural spatial variability in ecosystem carbon stocks, and limited capacity to determine accurately the baseline ecosystem carbon stocks that make meaningful carbon accounting possible. Similarly the inability to predict emissions accurately from livestock means that the impact of mitigation options cannot be measured. However, in each of these cases it is clear that enabling technology and appropriate policy incentives could nevertheless lead to significant reduction in emissions or increased carbon sequestration, albeit changes that may be both difficult to measure and difficult to bring into trading schemes.

Much of the terrestrial sequestration potential involves spatially extensive activities, where small contributions per unit land area collectively contribute significantly through application over large areas. This extent means that their widespread adoption, as might occur by their inclusion in a CPRS and a high carbon price, could see them transform rural landscapes. This provides the opportunity for carbon sequestration to drive many desirable and needed outcomes; for example, for biodiversity and ecosystem restoration, for salinity abatement or to improve stream water quality. Additionally, some of the options provide the means to generate income streams for land-owners that may increase and diversify farm incomes. Their extensive unplanned application, however, may lead to adverse outcomes for other environmental benefits and change rural livelihoods and commodity supplies.

There is also the opportunity to establish synergies between the various options where by the issue of saturation of carbon sinks in forests can be overcome by sustainable harvesting and regeneration of biomass, for production of biochar, which can be directly stored in the soil, or production of bioenergy, displacing fossil fuel combustion.

1.6 Institutional, economic and related frameworks

In addition to the levels of overlap and interconnection between options, there are significant economic, social and institutional issues which will impact on the realisation of gains in GHG mitigation and sequestration. In the final chapter, which covers environmental plantings, we deal with institutional, economic and related frameworks in addition to the biophysical elements of GHG sequestration/mitigation. These biophysical elements vary in the level of certainty around potential – but research and assessment can narrow these certainty bounds within the existing scientific understanding of carbon cycling and land management. There is also an improving understanding of how economic estimates and modelling can inform the tradeoffs between market and non-market values. However, the institutional and adoption elements are less well represented in the current conversations surrounding the design of the CPRS and of the various existing and proposed systems for emission reduction.

In the absence of a systemic approach which includes institutional and adoption realities, there will be barriers to the achievement of the levels of sequestration and mitigation possible. Importantly, due to negative externalities of carbon markets, there is a real possibility of a new series of environmental problems, impacts on production systems and knock-on effects through the economy. These issues are discussed in more detail in Chapter 12 which covers institutional, economic and social dimensions.

The potential perverse outcomes range from diversion of food production lands at a time where food security is a growing priority to impacts on environmental values such as biodiversity, weed and feral animal control and off-site changes. Equally, co-benefits need to be understood so that investment decisions and policy design are undertaken in the light of both positive and negative externalities. To achieve this there is a need for a systemic program of further research and policy development at a national and state level which covers the range of biophysical, economic, social and institutional dimensions in an integrated way.

1.7 Research and policy development

The analysis undertaken in this report has helped identify and articulate the research and policy development that is required to enable Australia to utilise rural land use in an optimal manner to biosequester or mitigate GHG emissions.

Future *biophysical research* needs to focus on narrowing the uncertainty bounds around carbon sequestration rates, yield curves over time including time to carbon sink saturation and level of sink saturation, and emissions regimes. A clear focus on the link between land management practice and practice change on GHG dynamics will be central, not just at the farm level but at regional levels and across the value chain for agricultural products.

Future economic research needs to focus on the *economics of land management* (including estimates of project and property viability, costs, benefits, liabilities, from the perspective of altered financial incentives of multiple land use options; estimates of non-market values and impacts on NRM goals such as biodiversity and water quality and availability, and impacts on food and fibre production and rural livelihoods). There is a need to explore the business dimensions of realising sequestration and mitigation options – with investigation of the co-benefits and tradeoffs both at property and regional scale.

Effective implementation of new approaches and industries will depend on the *institutional settings* – with research required on policy conditions (coverage of CPRS; specifically designed market-based instruments for environmental regulation; payment for environmental services; biodiversity and social licence to operate under CPRS, voluntary markets and negotiated agreements); market design (barriers, property rights options and dimensions, transition of market designs and a regime for maintaining carbon sinks once they have saturated); and governance arrangements (enabling organisations, engagement models and defined roles and responsibilities e.g. of regional NRM bodies, peak bodies and agencies).

The other plank in this integrated research agenda concerns an understanding of the *drivers and barriers* to adoption of mitigation activity. This research will concentrate on information and exchange and the connection to community capacity, decision making processes, cultural ties, identity, and relationship to land, project development initiatives and the behaviours related to external drivers such as market structures.

The breadth of this proposed research agenda reflects the substantial change that the opportunity for terrestrial sequestration and mitigation brings.

2 Carbon positive management of regrowth vegetation and remnant forest

John Raison, Christian Witte, Jim Walls, Jo Kitchen, John Carter, Bruce Goulevitch, Andrew Clark and Gordon Guymer

2.1 Definition and scope

Clearing of woody vegetation results in CO₂ release from the above and below-ground components of the trees, possible changes in soil C stocks, and direct emissions of non-CO₂ GHGs in fire. Retention of regrowth originating from earlier clearing will result in accumulation of C in biomass for many decades as forest stands develop and eventually reach site 'carrying capacity'. Subsequent land use will also affect GHG balances e.g. conversion of woodland to grazed pasture will result in increased emissions of methane from livestock. Below we consider recent clearing rates, the related GHG emissions, and the opportunities for reduced GHG emissions from clearing in future.

Terms used throughout the chapter are defined below.

Remnant vegetation: is defined as vegetation mapped as remnant on a regional ecosystem or remnant vegetation map. For woody vegetation to be mapped as remnant the dominant canopy must have >70% of the height and >50% of the cover relative to the undisturbed height and cover of that stratum and is dominated by species characteristic of the vegetation's undisturbed canopy (http://www.epa.qld.gov.au/nature_conservation/plants/remnant_vegetation_in_queensland/).

Non-remnant vegetation: the vegetation that doesn't meet the remnant vegetation statuses. For woody vegetation this could also be described as regrowth.

Assessable Regrowth: is woody vegetation on leasehold land that has not been cleared since December 31, 1989 and is not mapped as remnant regional ecosystem by the DERM Herbarium.

Non-assessable Regrowth: is any other woody vegetation that is not mapped as remnant regional ecosystem by the DERM Herbarium.

2.2 Analysis

The State wide Land cover and Trees Study (SLATS) has monitored tree clearing in Queensland from 1988 to 2007. Figure 2-1 below is taken from the 2006-2007 SLATS report (DNR&W 2009) which was recently released. The reporting period is approximately winter 2006 to winter 2007. This includes the December 2006 expiry date for broad scale vegetation clearing permits implemented through the *Vegetation Management Act 1999*. The annual clearing rate for 2006-07 was 235,000 ha/yr which is a reduction of 37% from the previous year (2005-06) rate of 375,000 ha/yr.

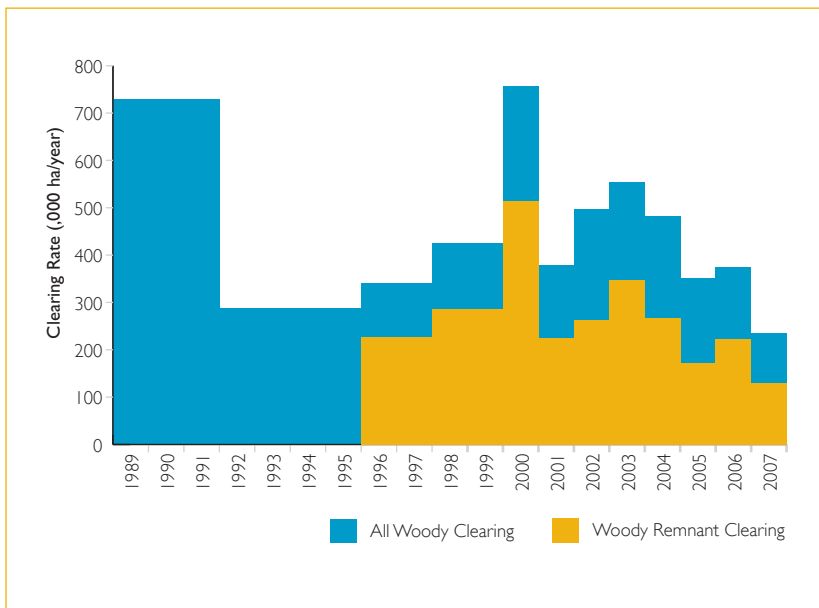


Figure 2-1: Tree clearing trend in Queensland (1988-2007), woody remnant clearing is only separated from total clearing after 1996.

2.2.1 Clearing impacts on GHG emissions (expressed as carbon dioxide equivalents, CO₂-e)

Data from the SLATS monitoring and other studies on eucalypt, acacia and rainforest sites were assembled to calculate the relationships between stand basal area and biomass (Lucas *et al.* 1998; Burrows *et al.* 2002) for the 1997–99 SLATS report (DNR, 2000).

These equations were applied to pre-clearing live stand basal area as mapped by SLATS to estimate live above and below ground (root) biomass. It is estimated that approximately 17.2 million tonnes (Mt) of dry biomass or 8.6 Mt of carbon were contained in biomass cleared during the 2006–07 period. This compares with 22.5 Mt of biomass and 11.2 Mt of carbon in 2005–06. The estimated eventual emissions, (CO₂-e) from cleared above and below ground live woody biomass for 2006–2007 is 31.55 Mt. This compares with 41.24 Mt for the previous year (2005–2006). The estimated CO₂-e emissions from tree biomass between 1988 and 2007 are shown in Figure 2-2.

At this stage no account has been made for dead timber cleared or for reduced biomass stocks contained in cleared regrowth forest. While the biomass cleared will eventually decay, the rate of release of CO₂ depends to a great extent on the clearing method and post clearing management of woody debris (Henry *et al.* 2002). In particular, if fire is used to remove heaped debris, there will be emission of non-CO₂ GHGs. To account for those extra GHG emissions, the above estimates of CO₂ emissions (Figure 2-2) were increased by 9% based on the modelling that is conducted in Australia’s NGGI and National Carbon Accounting System (NCAS).

Further, there is a need to account for soil C emissions resulting from tree clearing and subsequent land use change. These are greater following conversion to cropping, than they are with conversion to grazed pasture. On average the loss of soil carbon (0–30 cm) during the transition from trees to agriculture (arable and/or grazing) in Queensland is ~ 10% based on NCAS modelling (Robert Waterworth, pers. comm.). This is about 10% of the losses of C that occurs from biomass. Thus the combined emissions from fire and soil C are roughly equivalent to 20% of the direct emissions from cleared biomass, and this scalar has been applied to the figures shown in Figure 2-2. Inclusion of the fire and soil C emissions in the estimates of emissions from biomass, made using the SLATS methods, will produce estimates of total GHG emissions that are consistent with those produced by the NCAS.

When the fire and soil C emissions are added, the estimated eventual (delays occur due to decomposition processes) total GHG emissions resulting from clearing in 2006–07, are ~ 38 Mt CO₂-e. Note that these are the emissions associated with new clearing in 2006–07, and do not include C uptake by regrowth resulting from previous clearing events. The emissions in Queensland are about 65% of the national GHG emissions resulting from deforestation (DCC, pers. comm., 2009).

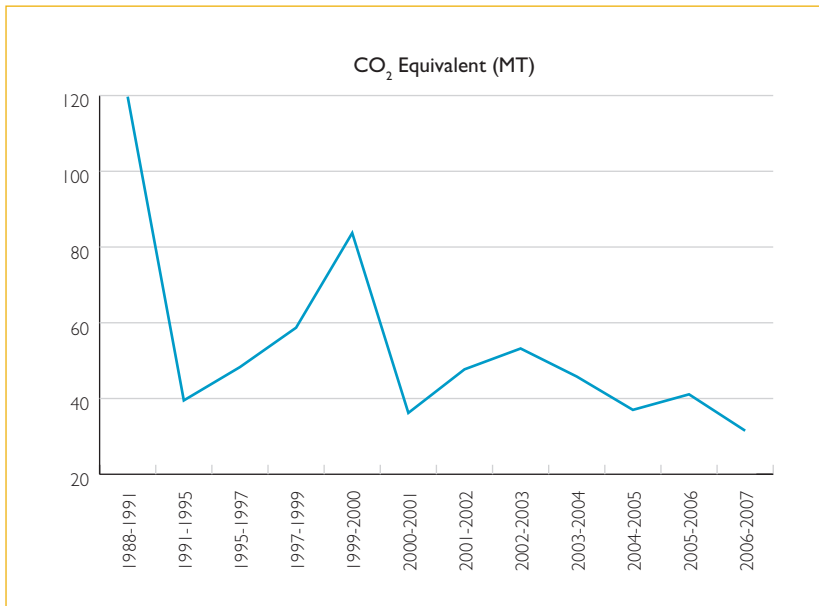


Figure 2-2: GHG emissions expressed as CO₂ equivalents from tree biomass after clearing (1988-2007).

2.3 Relevant policy/legislation relating to land clearing

2.3.1 Vegetation Management Act 1999 - conditions regulating remnant vegetation clearing

The Vegetation Management Act 1999 regulates the clearing of remnant vegetation on freehold land, and of remnant and some non-remnant vegetation on state tenures (<http://www.nrw.qld.gov.au/vegetation/clearing/index.html>).

Some clearing activities may also be undertaken without a permit under Schedule 8 of the Integrated Planning Act (IPA). There may be other permit or contract conditions, or other Commonwealth, state or local government requirements that restrict vegetation clearing.

Applications to clear are made for:

- operational work for the clearing of vegetation where the clearing is made assessable under Schedule 8 of the IPA;
- a material change of use; and
- reconfiguration of a lot.

If the application is for operational work then the type of vegetation clearing can be:

- under a project declared to be a significant project under the State Development and Public Works Organisation Act 1971, section 26;
- necessary to control non-native plants and declared pests;
- to ensure public safety;
- for establishing a necessary fence, firebreak, road or other built infrastructure, if there is no suitable alternative site for the fence, firebreak, road or infrastructure;
- as the natural and ordinary consequence of other assessable development for which a development approval as defined under the Integrated Planning Act 1997 (IPA) was given, or a development application as defined under the IPA was made before 16 May 2003;
- for fodder harvesting;
- for thinning;
- for clearing of encroachment; and
- for an extractive industry.

2.3.2 Conditions regulating regrowth vegetation clearing

In addition to the reasons for applying for clearing remnant vegetation, regrowth can be cleared on leases issued under the Land Act 1994 for agriculture and grazing purposes require a permit unless under PMAV category X.

Permits may be given for 'Assessable Regrowth'.

- Regrowth can be cleared without a permit on non-leasehold lands.
- Regrowth may not be cleared if a successful prosecution occurred previously.

2.4 Sequestration opportunities

2.4.1 Maximum potential CO₂-e sequestration rate based on 2006-2007 clearing rates

Permits for broad scale remnant vegetation clearing expired on 31 December 2006. As a result, a substantial decline in tree clearing occurred in 2006-2007 as shown in Figure 2-1 and Figure 2-2. A further decline is likely in 2007-08 and it would seem unlikely that tree clearing rates beyond 2008 would rise above the 2006-07 figures. Therefore, the 2006-07 rate of 38 Mt CO₂-e could be used as an upper estimate of potential CO₂ emission from future clearing. This estimate is simplistic and likely to be a significant overestimate. The value of 38 Mt includes regrowth clearing, fodder harvesting, clearing for settlement, infrastructure and mining, and illegal clearing of remnant vegetation. Some of these activities are very likely to continue. However, through reduced clearing in the future considerable reductions could be possible and *a proportion of this 38 Mt is an opportunity for reduced emissions.*

It's important to note that a considerable amount of regrowth may not meet the definition of Kyoto Land or Kyoto Forest. However, there is a potential for accumulation of a significant stock of biomass C if this regrowth is allowed to develop over time.

2.4.2 Opportunities relating to regrowth clearing on freehold land

As a result of existing legislation there is unlikely to be significant clearing activity on leasehold land. Hence there is limited opportunity for carbon emission reduction by reducing clearing on leasehold land. The one area that could be investigated further is fodder harvesting of Mulga. It wasn't possible to provide clearing or CO₂ equivalent estimates for Mulga harvesting in the timeframe provided. In addition, it may be possible that fodder harvesting results in a net C sink due to the low rates of decay of timber on the ground and subsequent re-accumulation of C in regrowth.

Broad scale clearing of remnant vegetation on freehold land is no longer permitted. However, clearing of regrowth on freehold land is possible under current legislation. This includes older regrowth (cleared prior to 1990) as well as that produced in recent times. It is not clear how this forest would be considered in any C trading framework. A change in legislation may be required or the implementation of other mechanisms which encourage the retention of regrowth of freehold land.

2.4.3 Emissions based on 2006-07 clearing rates for non-remnant vegetation on freehold land

For the year 2006–07, approximately 66,400 ha of non-remnant or regrowth vegetation was cleared on freehold land (DNR&W 2009). Without detailed modelling it is difficult to provide a reliable estimate of GHG emissions resulting from the clearing of non-remnant vegetation given the range of vegetation types and growth stages involved. A conservative estimate is that this will be approximately 50% of the emissions resulting from clearing an equivalent area of remnant vegetation. However, analysis of remote sensing data by the DCC shows that the average age of cleared regrowth is only 10-12 years, suggesting that this regrowth may contain much less than 50% of the C contained in cleared remnant vegetation.

Based on the assumption of 50% C content, Figure 2-3 provides a breakdown of CO₂ emissions from freehold and leasehold land clearing separated by remnant status. This suggests that the freehold regrowth clearing in 2006-07 would result in emissions of about 7 Mt of CO₂-e.

Thus, if the 2006-07 rates continued in future years, reduced clearing of non-remnant forest on freehold land could result in an emission reduction opportunity of up to 7 Mt annually. Over a period of 40 years (2010 to 2050) this equates to 280 Mt. That's simply looking at the CO₂-e retained by not clearing. Other considerations are:

- there will be the on-going sequestration of retained regrowth until site C carrying capacity is reached; and
- within a 40 year timeframe there will be a considerable amount of re-clearing of the same patches of vegetation.

The net effect of these two factors can be considered by estimating the change in the average C stocks of regrowth forest across the landscape.

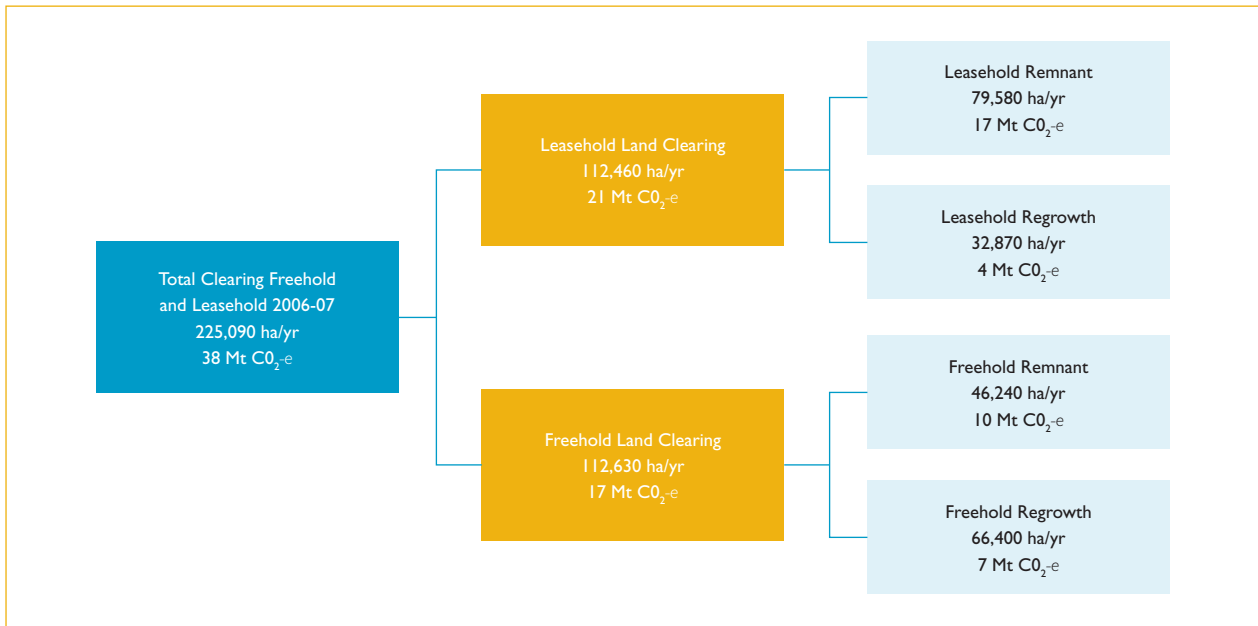


Figure 2-3: Breakdown of CO₂ emissions from freehold and leasehold land clearing by remnant status (DNR&W, 2009).

2.4.4 Trend in non-remnant (regrowth) clearing on freehold land

A total of approximately 1.1 million ha of regrowth forest was cleared on freehold land between 1995 and 2007. Brief analysis using the Remnant Ecosystem data (RE, Version 5.0), the digital cadastral database and the foliage projected coverage (FPC; Armston *et al.* 2009) estimates that the total area of non-remnant (possibly regrowth) forest on freehold land is approximately 5,560,000 ha. Forest here is defined as FPC > 11% which approximates a Crown Cover of 20% (Scarth *et al.* 2008) and is the definition used for the National Carbon Accounting System (AGO 2003).

A considerable proportion of this forest is unlikely to be cleared in future, such as fragmented remnants of the original vegetation e.g. wind breaks, shade areas, as well as riparian vegetation, vegetation on steep slopes, under voluntary conservation agreements and in low productivity areas where the investment to clear is not viable. However, it's also likely that a substantial proportion of the approximately 5.5 million ha of forest on freehold land could be legally cleared in future. There are many factors, and complex interactions, that could determine future rates of regrowth clearing:

- Legislative change.
- Climatic variability affecting agricultural opportunities.
- Carbon price.
- Human behaviour:
- Risks/negatives (Future GHG liabilities).
- Agricultural markets/prices.
- International climate change negotiations.
- Commonwealth - State negotiations.
- Sustainability implications (e.g. increased grazing pressure, other environmental issues).

It appears that the observed decline in clearing rates of regrowth on freehold land (Figure 2-4) may not be a supply issue, but could be driven by economic conditions and other factors such as those listed above. Further analysis is required to provide a more accurate estimate of the area of regrowth forest which is likely to be cleared again under current legislation. As a starting point, we assume that current rates of regrowth clearing will continue in the near term – however, we stress that this is an area of very high uncertainty, with considerable consequences for future GHG balances.

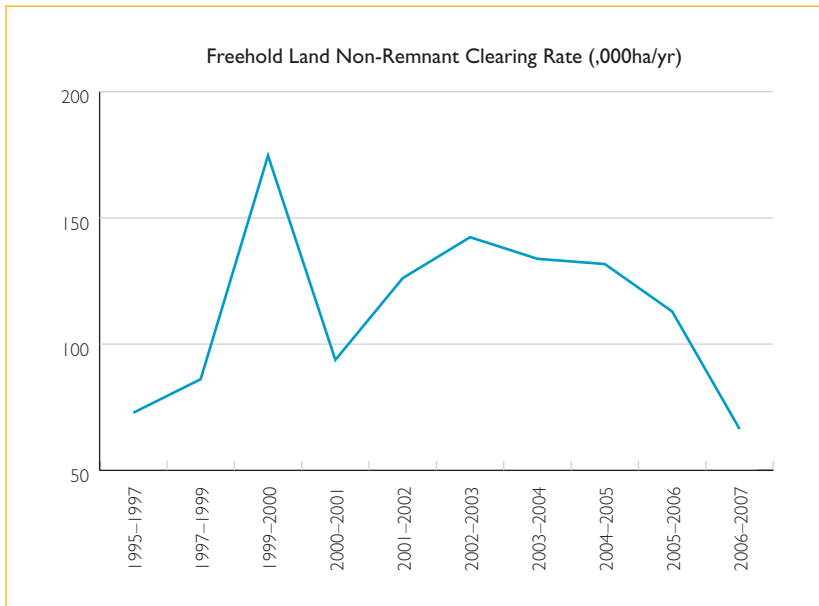


Figure 2-4: Clearing trends for non-remnant (regrowth) vegetation on freehold land in Queensland (1988-2007).

2.5 Other Issues

It is noteworthy that there has been more than a decade of R&D by the Queensland Government (SLATS program) and by the DCC (development of the NCAS to deal with Article 3.3 under the Kyoto Protocol) that has resulted in a good capacity to estimate the consequences of differing clearing strategies/outcomes for GHG balances. Thus uncertainties in this area result more from what future clearing patterns will be, rather than from our capacity to estimate the GHG consequences. Given the importance of the dynamics of regrowth for future GHG balance, greater attention should be given to strengthening the basis for estimating spatial and temporal change in this forest. The GHG consequences of changes in land clearing activities in Queensland are estimated by the Australian government, and reported in the NGGI, and under UNFCCC obligations.

Reduction in land clearing is likely to have some co-benefits, particularly for biodiversity, in many regions. An overall concern is that if the density and area of woody vegetation increases then grazing pressure could increase on other areas thereby increasing land degradation unless there is a commensurate decline in the number of grazing animals. Increasing tree density and foliage mass may also predispose systems to a higher probability of drought death. There may also be consequences for increased fire risk that need to be considered.

2.6 Contributors

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2.7 Research Groups, Activity and Focus

Groups

- Queensland Department of Environment and Resource Management

Research

- Assessment of tree clearing trends in Queensland from 1988 til 2007
- CO₂ emissions related to that clearing
- Identifying the main opportunities for sequestration

2.8 References

Armston, J, Denham, R, Danaher, T, Scarth, P, Moffiet, T (2008). 'Prediction and validation of foliage projective cover from Landsat-5 TM and Landsat-7 ETM+ imagery for Queensland, Australia' *Journal of Applied Remote Sensing*. 2009.

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Scarth, P, Armston, J, Danaher, T (2008). 'On the Relationship between Crown Cover, Foliage Cover and Leaf Area Index' *Proceedings of the 14th Australasian Remote Sensing and Photogrammetry Conference* Darwin, Australia, October 2008

Table 2-1: Methodology for estimating potential, attainable and base greenhouse gas sequestration/mitigation for regrowth.

Option	Carbon positive management of regrowth vegetation and remnant forest	
Current or Business as Usual Net Carbon Storage (Mt t CO₂-e) from 2010 to 2050	Significant GHG emissions from current clearing. Significant ongoing accumulation of C in regrowth resulting from earlier clearing events.	
Net Potential* Carbon Storage (Mt CO₂-e) from 2010 to 2050	Australia	2238 Mt over 40 years 56 Mt/yr
	Queensland	1520 Mt over 40 years 38 Mt/yr
Functional Unit and Basic Algorithm Used to Calculate per Unit CO₂-e	Tree clearing mapped using remote sensing; conversion of foliage projective cover (prior to clearing) to basal area and then to biomass. Models used to estimate biomass and soil C change, and non-CO ₂ GHG emissions from fire.	
Scaling Up Process	Remote sensing and ecosystem modelling used to estimate spatial and temporal change.	
Attainable* Net Carbon Storage (Mt CO₂-e) and factors driving this translation	Queensland	280 Mt over 40 years 7 Mt/yr This could be achieved mainly through reduced non-remnant (regrowth) clearing on freehold land, and by offsetting remnant clearing for infrastructure development and other clearing that will occur. Note that retention of regrowth will result in increase of ecosystem C stocks over millions of ha of land for the next 50 years.
Base* Net Carbon Storage (Mt CO₂-e) and factors driving this translation	Queensland	Uncertain, and depends on many 'drivers' outlined in the text.

* See Chapter 1 Section 1.2 Methodology for explanation of potential, attainable and base.

3 Reduce livestock enteric emissions and structural change in industry

Ed Charmley

3.1 Definition and scope

Livestock GHG emissions in Queensland are predominantly methane with 95% originating from cattle (Table 3-1). Almost all CH₄ (94%) in livestock agriculture originates from enteric fermentation. N₂O contributes approximately 3% of total livestock emissions in Queensland (Department of Climate Change, 2008). This report deals predominantly with CH₄ emissions from cattle. However, many of the assumptions made about cattle also apply to sheep which are the second most important source of livestock GHGs. The contribution made by sheep to GHG emissions is lower for Queensland (2.6%) than for Australia as a whole (19%) because of the relatively small sheep population in Queensland (4.4 million or 5% of the national flock). Furthermore, their numbers are trending down.

Table 3-1: Estimates of livestock GHG emissions for Australia and Queensland (,000 tonnes CO₂-e, Department of Climate Change, 2008).

Source	CH ₄		N ₂ O	
	Australia	Queensland	Australia	Queensland
Cattle	46084	20211	1042	569
Sheep	13547	564	-	
Other livestock	1543	487	543	87
Total	61201	21263	10585	655

3.2 Analysis

Methane from ruminants is a significant proportion (about 67%) of agricultural emissions in Australia and agriculture accounts for about 14% of total GHGs. It is a by-product of rumen microbial fermentation and is an inevitable consequence of ruminant production, accounting for between approximately 3 and 12% of the gross energy consumed by ruminants (Johnson and Johnson, 1995). This variation is driven largely by the nature and quality of the diet; generally the higher the diet quality, the lower the methane emissions per unit of intake.

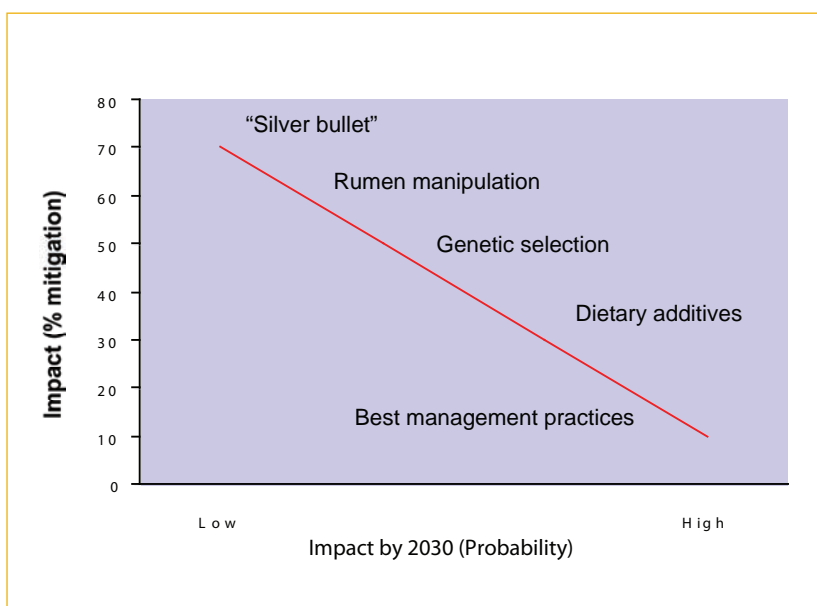


Figure 3-1: Various mitigation options, likely timeframe for adoption and potential impact on emissions.

There is no single, high impact strategy currently available that could have a significant impact by 2015, without major policy and research intervention. Rather a range of approaches, tailored to specific components of the industry will be required for meaningful reductions (10-20%) in enteric methane in the short term (Figure 3-1). In the longer term, greater reductions in GHG emissions could be achieved, but this would require significant technological development and societal change. Figure 1 compares options in terms of their timeframe for realization and their likely impact on methane emissions. It shows a qualitative relationship, where, in general, the bigger impacts are likely to occur further into the future.

3.2.1 Short-term (by 2015, 10 to 20% reduction in emissions).

Best management practices to reduce methane through management intervention. This would require policy incentives but include:

- Improved pasture management and feeding practices.
- Improved reproductive performance in the national beef herd.
- Promotion of known feeding strategies to reduce methane (ionophores, dietary fats, legumes).
- Changed land use practices in pastoral zone (cattle, forestry, savannah burning, etc) could lead to win-win outcomes particularly with C trading.

3.2.2 Medium term (by 2020, 20 to 40% reduction in emissions)

Medium term technology options include:

- Advance some of the more promising plant-based compounds as feed additives; e.g. tannins and saponins in legumes. These compounds are already in feeds but a lack of research means we don't fully understand how to exploit them. An advantage is that many are already agronomically suited to current production systems (e.g. leucaena in northern Australia) and could be rapidly adopted.
- Concerted effort in vaccines may offer early gains but significant work needed in basic microbiology and immunology.
- Development of specific anti-microbials (e.g. bacteriophages) to knock out methanogens.

3.2.3 Long term (by 2050, 40 to 80% reduction in emissions)

Medium term technology options include:

- Rumen manipulation. Alter fermentation pathways to provide alternative H sinks and to eliminate methanogens.
- Genetic improvement. Marker assisted genetic selection for reduced methane emissions in sheep and cattle. Benefits are bred into the animal and gains are permanent in the whole population.

3.3 Defining uncertainty

The methodology for validation of current livestock GHG emission levels needs further refinement, but is critical if the impact of mitigation strategies is to be measured. Lifecycle analysis is essential if perceived emission reductions in one sector can be nullified by perverse outcomes in other sectors.

Table 3-2: Factors influencing the estimation of livestock methane emissions in Queensland.

Factor	Comment	Range in estimated methane emissions
Relationship between DMI and CH ₄ production	There is relatively little information on this relationship under extensive farming conditions, as distinct from intensive management. Early research based on a very small dataset suggested tropical diets were responsible for higher emissions per unit of DMI than temperate diets. This assumption is being questioned now based on recent data and future estimates will likely be reduced.	30%
Estimation of diet quality and DMI for livestock	DMI cannot be measured directly under extensive grazing conditions encountered in much of Queensland. The current equation used to develop national inventory is based on a relatively small dataset under controlled feeding conditions. Pasture heterogeneity, grazing pressure (stocking rate), selective grazing and the physiological status of the animal all influence DMI and cannot be adequately estimated in Queensland at present. Ongoing modelling work will reduce the uncertainty around this key factor.	50%
Assessment of livestock numbers and herd structure	ABARE and ABS statistics provide good historical estimates of livestock numbers and age classes. However these can change quickly in times of drought or good rains and they do not account for variability in animal weights and condition; both key drivers to methane emissions.	10%

There is a high level of uncertainty around the current GHG emissions from cattle and sheep under extensive grazing conditions for most of Queensland. This report will focus on defining the uncertainty around the magnitude, and scope for mitigation, of CH₄ in cattle. The National Greenhouse Gas Inventory Committee (2005) calculations used to estimate emissions are based on livestock numbers, estimates of dry matter intake (DMI) and thus energy intake, and one of two relationships relating CH₄ production to energy intake, one for temperate and one for tropical feeds. Various defaults are used depending on species and class of animal (growing, lactating, etc).

The NGGI approach gives an indicative value regarding the contribution of livestock to GHG emissions in Queensland. However it cannot account for the many factors that influence GHG and particularly CH₄ emissions. These are listed in Table 3-2 with an estimated range in emissions, based on known influences these factors have on methane emissions. For Queensland in particular, the vast areas under grazing and their inherent variability in productivity and management mean that accurate estimates are difficult on a State-wide basis. We have adopted a regional basis for estimating emissions, using ABARE classification. While this is a coarse approximation to bioregions, it does differentiate among production systems predominating in different regions and allows for regionally specific interrogation of production scenarios.

Using a modelling approach (Charmley *et al.* 2008), several scenarios were tested to assess the likely magnitude of change in CH₄ emissions in response to these three factors listed in Table 3-2. The modelling exercise was restricted to 5 bio-regions accounting for over 84% of the Queensland cattle population. The estimate of CH₄ emissions using the current equation (Hunter, 2007; Kurihara *et al.*, 1999) used by the NGGI was 10.9 Mt CO₂-e/year. We believe a more accurate figure is 7.8 Mt CO₂-e/year obtained by using an algorithm based on recent data from 7 diets which evaluated the effect of grass species, protein level and diet quality (Charmley and Kennedy, unpublished).

Under northern grazing conditions diet quality has a profound effect on DMI and two diet quality scenarios are compared (Table 3-3). Because diet quality affects rate of gain, which in turn influences herd structure the methane emissions response is complex. The modelling scenario investigates the effect of increasing mean seasonal diet digestibility from 56% (lower than normal) to 64% (higher than normal). Although this wide range in diet quality increased methane emissions in individual cattle, because daily intake was increased, it also altered performance and herd structure; growing cattle were slaughtered at younger ages allowing for increased numbers of breeding cattle. As a result, the overall the impact on CH₄ emissions was much smaller than would be anticipated from the effects on individuals.

Table 3-3: Influence of diet quality on CH₄ emissions (CO₂-e) from individual animals and the Queensland beef herd after accounting for changed herd age structure.

Digestibility (%)	56	64	Response, %
Per adult equivalent (t/yr)	1.3	2.1	+61
Total herd (million t/yr)	12.6	13.6	+8

The final comparison assessed the impact of eliminating cattle from those areas of Queensland in which commercial kangaroo harvesting is practiced as suggested by Garnaut (2008) based on the paper of Wilson and Edwards (2008). Across the 5 broad acre zones and regions in the model, total cattle numbers would be reduced from 9.7 million to 5.8 million. Methane emissions would be reduced from 12.7 to 7.6 million tonnes CO₂-e/yr. For the whole of Queensland the extrapolated reduction in CH₄ by eliminating cattle from areas where kangaroos are harvested would be 5.5 million tonnes CO₂-e/yr or 37%. Improved efficiency of production in the remaining portion of the State could increase live weight gain per unit of CH₄ emitted which would offset to some extent the loss of beef production in kangaroo harvesting areas. It should be pointed out that such a scenario is unrealistic and simplistic. The extent to which ruminants may be replaced by kangaroos will be driven by markets, economics and importantly, societal and social drivers as well as national policy directives.

Queensland versus national emissions This report focuses on GHG emissions in Queensland. While there are some assumptions that apply equally to the rest of the country, there are many factors that make a simple projection to the whole country unsatisfactory. If measures effect a 10% reduction in Queensland they will not automatically effect a 10% reduction in the whole of Australia. Factors that make such an extrapolation unsatisfactory include:

- Predominance of the beef sector versus other livestock sectors. Beef cattle account for 98% of cattle in Queensland versus 90% in Australia and only 60% in Victoria. Dairy cattle have higher DM intakes and are generally fed higher quality rations under intensive management systems.
- Proportionally smaller contribution made by the sheep sector to ruminant livestock
- Predominance of extensive grazing systems. The majority of cattle in Queensland graze extensive, low yielding, low quality pastures. The management systems that operate under these conditions and the options available for mitigation technologies are quite distinct to those available in southern areas of the country. For example, methane emissions from northern systems are more responsive to improved management (e.g. increasing calving rate) than southern systems, simply because the baseline is lower. In contrast, the option for frequent dosing of antimethanogenic dietary supplements is impractical for many extensively managed cattle, whereas such a measure is readily achieved in the dairy or feedlot sector.
- *Units for reporting* It is tempting to take methane emissions of individual animals and simply scale up to the herd, regional and state level. But this is not a straightforward exercise and can be misleading. The herd, region and state all have a spatial dimension, therefore care is needed to switch reporting from a per animal or unit of product basis to a per area basis. Frequently, factors that reduce methane emissions from an individual animal on a daily basis do not have the same impact on a per area basis. This is because factors such as growth rate, stocking density and herd composition (the mix between reproductive and growing cattle) inevitably change. Therefore it is prudent to express livestock emissions on both a per unit product (e.g. marketable live weight or red meat) and a per unit area basis.

3.4 Risks and barriers to implementation

The main barriers to implementation are the understanding and quantifying the extent of GHG emissions from an extensively managed livestock sector with a highly diverse and responsive management ethos. The inability to predict emissions with accuracy means that the impact of mitigation strategies cannot be measured and hence credited for. Furthermore, if the point of obligation for carbon accounting will be at the processor, then adoption of mitigation practices will be very low. Policy intervention or new market signals will be required to increase uptake of low emissions livestock production. In spite of significant research effort, technologies to reduce methane emissions in livestock have not been highly successful. Until recently, little was known about the metabolism and ecology of methanogens in the rumen, thus approaches to alter their metabolism or populations were broad-spectrum in nature. The efficacy of many dietary products has proved to be less than purported by the manufacturers. Effects are often transient or may work under some conditions but not under others. It is believed that a large number of products have been developed but not marketed or accredited. These will enter the market if carbon trading schemes globally make them economically viable. The efficacy of these newer products is proprietary information and unknown. Today, advances in understanding the ruminal microbial genome should allow for targeted and specific approaches that are likely to markedly reduce methane emissions in the longer term.

The extensive nature of the Queensland livestock industries is not conducive to widespread adoption of many mitigation strategies. This narrows the options available to the industry, relative to intensive livestock enterprises. However, on the positive side, large

improvements in productivity will be easier to achieve in extensive livestock systems than intensive livestock systems. Therefore the possibility of improved/ altered management is likely to reduce methane emissions per unit of product more so in Queensland than in, for example Western Europe or New Zealand.

3.5 Compliance and auditing

Compliance and auditing is currently very difficult. Significant research effort will be needed to effectively measure emissions and to populate models with verifiable data. If auditing for a carbon pollution reduction scheme is conducted towards the end of the supply chain it will not account for the diversity of production strategies and mitigation efforts carried out by individual producers. However, auditing at the farm gate is currently impossible. Major research effort and/or policy incentives will be required to develop an elegant and responsive system that rewards individual producers for optimizing mitigation and sequestration strategies on the property.

3.6 Other benefits and consequences

The aspiration goal of making livestock farming carbon neutral will only be possible when viewed at the whole of system level. At the animal level, there is a positive relationship between improved productivity and reduced methane emissions per unit product. There are options available today that can improve productivity, if they are economically viable. Policy tools and carbon incentive schemes will alter the economic drivers of livestock production. If livestock can be raised more efficiently, for example, on a smaller area of land this allows for integration of forestry options on land freed from grazing at the property and regional level. Alternatively, if the sequestering potential of soil across large land areas currently used for extensive beef grazing can be used to offset livestock emissions, then extensive grazing systems may yet remain a dominant feature of the landscape. While macropods offer a simplistic solution to reducing methane emissions from red meat animals, the scope for this paradigm shift is currently limited. It would require major investment into marketing, social science, production systems and animal welfare issues.

3.7 Lateral thinking

Clearly, there is uncertainty about the magnitude of GHG emissions from livestock in Queensland. Nevertheless, as a State, Queensland contributes the largest share of the nation's livestock GHGs. The predominance of extensive grazing in the industry offers not only limitations to mitigation technology use but also potential for win-win outcomes. These will be derived by better matching landscape use to diversified revenue streams and management practices. To look at livestock GHG emissions in isolation from soil and plant C sequestration, burning and alternate land use is meaningless. Livestock are raised in an integrated biophysical system underpinned by complex social drivers. Livestock should be considered as an integral part of a whole of system approach to C budgeting, where the real potential for reducing methane emissions from livestock will have a significant impact.

3.8 Contributors

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3.9 Research Groups

CSIRO, Livestock Industries

- Rockhampton; tropical systems, measurement techniques
- Brisbane; rumen manipulation, measurement techniques
- Perth; novel plants for low methane emissions

Universities

- Melbourne, Wollongong, UNE; UWA

State Departments

- Victoria, Queensland, NSW
- CRC for Beef Genetic Technologies

3.10 Research Activity and focus

- Microbial manipulation in the rumen to reduce methanogenesis.
- Validation of methane emissions and management for mitigation in the rangelands.
- Novel plant compounds that inhibit methane production in the rumen.
- Vaccines (formerly) against methane producing microbes.
- Methane emissions from feedlots, intensive grazing environments.
- Measurement techniques (FTIR, Laser, SF₆, calorimeters).
- Genetic selection for lower methane emissions.
- Methane measurements and mitigation in dairy systems.
- Assorted methane mitigation abatement research (dietary supplements, probiotic inoculants).
- Selection for lower methane emissions.

3.11 References

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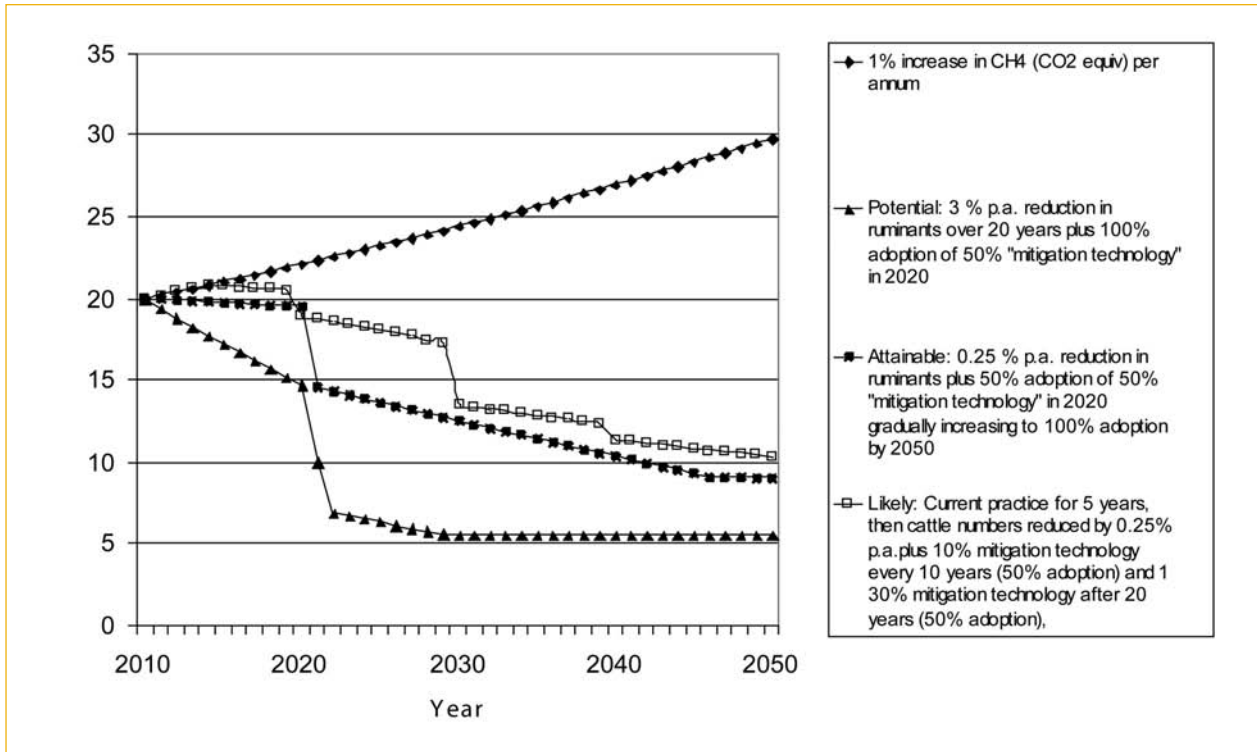
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Appendix I

Potential, Attainable and Base scenarios for CH₄ emissions (CO₂-e) in Queensland – 2010-2050⁸



⁸ In the potential scenario, a 3% p.a. reduction in livestock numbers would be required if all cattle in Queensland kangaroo harvesting areas were removed over the next 20 years as suggested by Garnaut (2008).

Table 3-4: Methodology for estimating potential, attainable and base greenhouse gas sequestration/mitigation for livestock.

Option		Reduce enteric emissions from livestock industries – individual animal emissions and industry structural changes
Current or Business as Usual Net Carbon emissions (Mt CO ₂ -e) from 2010 to 2050		2010 20 Mt 2050 29 Mt Assuming a 1% p.a. increase in GHG emissions based on data 1990 to 2006
Net Potential* Carbon emission reduction (Mt CO ₂ -e) from 2010 to 2050	Australia	2010 46 Mt 2050 12 Mt 25.9 Mt/yr 1042 Mt for 40 years
	Queensland	2010 20 Mt 2050 5 Mt 11.3 Mt/yr 453 Mt for 40 years Elimination of 4.2 million cattle from kangaroo harvesting areas Plus Development in 2020 of a mitigation technology capable of reducing methane emissions by 50% and being fully adopted
Functional Unit and Basic Algorithm Used to Calculate per Unit CO ₂ -e		Functional unit is the adult equivalent (450 kg bovine). Modelling approach published by Charmley <i>et al.</i> (2007). This takes into account the variability of diet quality, class and size of animal, herd structure and marketing options. It can run using several intake and methane emissions equations
Scaling Up Process		Calculate CH ₄ emissions for classes of livestock under different production conditions and used ABARE/ABS data to estimate livestock numbers by region and State.
Attainable* Net Carbon Storage (Mt CO ₂ -e) and factors driving this translation	Queensland	Emissions in 2050: 9 Mt 6.5 Mt/yr 259 Mt for 40 years Attainable: 0.25 % p.a. reduction in ruminants plus 50% adoption of 50% "mitigation technology" in 2020 gradually increasing to 100% adoption by 2050
Base* Net Carbon Storage (Mt CO ₂ -e) and factors driving this translation	Queensland	Emissions in 2050: 10 Mt 4.6 Mt/yr 184 Mt for 40 years Base: Current practice for 5 years, then cattle numbers reduced by 0.25% p.a. plus 10% mitigation technology every 10 years (50% adoption) and 1 30% mitigation technology after 20 years (50% adoption),

* See Chapter 1 Section 1.2 Methodology for explanation of potential, attainable and base.

4 Build soil carbon storage and mitigate nitrous oxide and methane emissions for cropped land

Ram Dalal, Jeff Baldock, Mike Bell and Peter Grace

4.1 Definition and scope

Sequestration of atmospheric carbon (C) in soil requires that the total amount of organic C stored in a soil is increased above its current level and that the increase is maintained into the future. The typical pathway for sequestration of atmospheric C in soils involves the capture of carbon dioxide (CO₂) by plants through photosynthesis, followed by a deposition of captured carbon into or onto soil. Although the processes of C capture and transfer to the soil occur continuously, losses through decomposition and mineralisation of soil carbon back to CO₂ also occur continually. For C to be sequestered in soil, the rate of carbon addition must be greater than the rate of carbon loss.

In addition to their influence on atmospheric C concentrations, soils can act as both sources and sinks for the other two main greenhouse gases: methane (CH₄) and nitrous oxide (N₂O). In this chapter we consider the role of soils in sequestering atmospheric CO₂ and mitigating emissions of CH₄ and N₂O in the cropping lands of Queensland. In Queensland, cropping lands include a variety of production systems based on grain crops, grain-pasture rotations, cotton, sugarcane and intensive horticulture. This report does not consider conversion of cropping land to permanent pastures.

4.2 Analysis Section

Defining the potential for sequestering carbon in the cropping soils of Queensland requires an assessment of the following factors:

- the land area being used for cropping
- the amount of carbon that can be captured and returned to the soil under different cropping systems and whether this can be increased into the future
- the potential storage capacity of soils used for cropping in Queensland, and
- the potential to enhance carbon storage through adoption of altered land management (e.g. reduced tillage practices). In addition to sequestering carbon, biological processes in soils can emit or consume nitrous oxide and methane. In the next section of this chapter, each of the factors and reductions in nitrous oxide (N₂O) and methane (CH₄) emissions are examined.

4.2.1 Land areas and yields associated with the major cropping systems in Queensland

The land areas devoted to the production of different crops and their associated yields in Queensland are given in Table 4-1. Estimates of area and yield are required to define whether increases or decreases in the amount of carbon returned to Queensland cropping soils are occurring. For each cropping system, the direction and magnitude of changes in crop yields through time differ. Wheat and sorghum crop area and yields for 2000 were obtained from Figure 4-1. Corresponding values for 2010 and 2050 were estimated by the project team. The area of land devoted to wheat crops over the last 25 years in Queensland has fluctuated between 0.4 and 1.1 million ha but average values have remained stable at approximately 0.75 million ha (Figure 4-1 top). Wheat yields may increase in the next 40 years as a result of improved germplasm and cultural practices; however, wheat cropping area may decrease if wheat grain prices do not increase and future rainfall predictions are correct. On the other hand, both the sorghum crop area and yields have been increasing over the last 15 years (Figure 4-2). The potential increase in area sown to sorghum into the future (0.80 m ha in 2050) will also contribute to the estimated reduction in the area sown to wheat (0.75 m ha in 2050). This increase is likely to have a positive impact on soil C stocks over a large area, especially if the proportion of land allocated to long fallows >9 months is reduced as suggested in Table 4-1. For cotton and pulse crops, a similar increase in yields through time is predicted and an expansion in the area of land devoted to pulse crops is expected in an attempt to reduce reliance on fertiliser sources of nitrogen. Similar increases in yield but not land area would be expected for sugarcane. Increased yields, unless achieved solely as a result of increases in harvest index, should result in increased returns of C to the soil in the form of crop residues or roots and potentially increase soil carbon content.

Table 4-1: Area under major crops and crop yields in Queensland in 2000 and future estimates of land area and crop yields for 2010 and 2050 provided by the project team.

Crop	2000*		2010		2050	
	Area (m ha)	Yield (t/ha)	Area (m ha)	Yield (t/ha)	Area (m ha)	Yield (t/ha)
Wheat	1.10**	1.77	1.10	1.8	0.75	2.0
Other winter cereals	0.22	1.50	0.25	1.8	0.25	2.0
Sorghum	0.56	2.22 *** (2.08)	0.60	2.53***	0.80	4.34*** (3.50)
Sugar cane	0.50	58	0.50	70	0.50	75
Cotton	0.13		0.15		0.2	
pulses	0.13	0.9	0.15	1.0	0.2	1.5
Other crops	0.04	1.0	0.05	1.0	0.05	1.0
Total cropped area	2.68				2.75	
Fallow	1.14				0.80	

*ABS 2003;

**Andries Potgieter;

***Estimated from Figure 4-1 (Andries Potgieter and ABS2003, ABS2004 and ABS2006). The group assessment indicates 3.5 t/ha as the realistic mean sorghum yields by 2050.

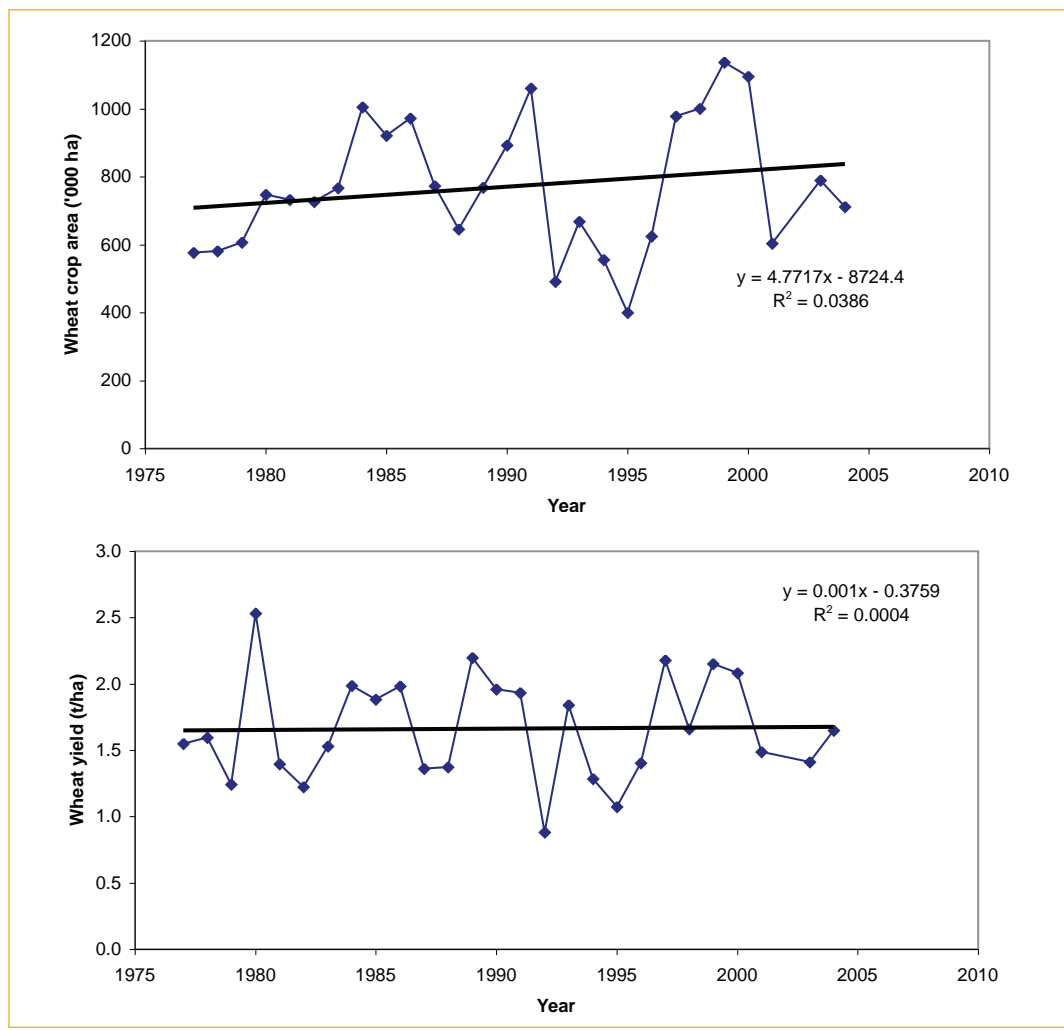


Figure 4-1: Trends in wheat crop area (top) and wheat crop yields (bottom), Queensland (Andries Potgieter and ABS2003, ABS2004 and ABS2006).

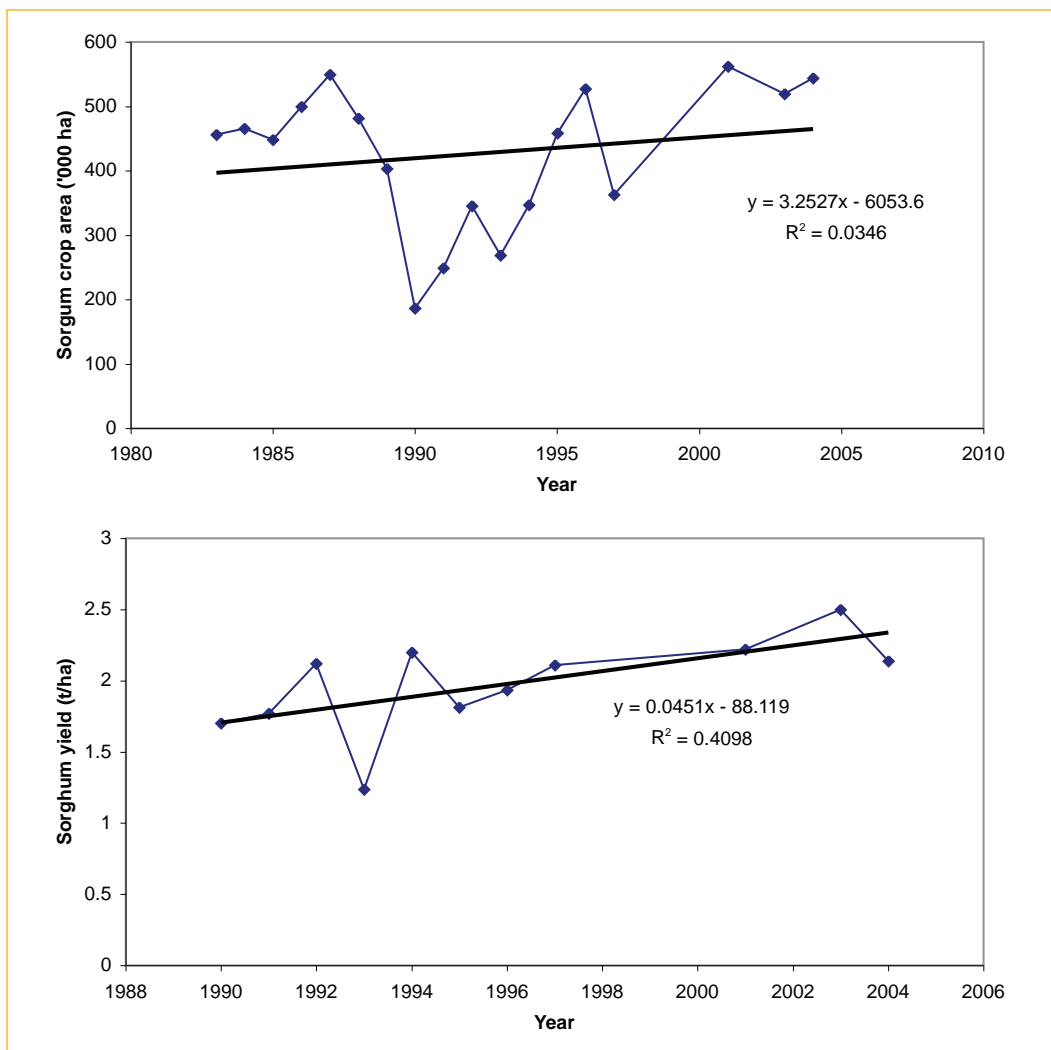


Figure 4-2: Trends in sorghum crop area (top) and sorghum yield (bottom), Queensland (Andries Potgieter and ABS2003, ABS2004 and ABS2006).

Substantial decrease in the total area of land allocated to fallows is not expected due to high variability of total rainfall and its distribution in Queensland and the dependence of crops on water stored in soil profile during fallow (Table 4-2). However, increasing No-till (NT) practices may reduce the frequency of long fallows due to a more efficient use of rainfall and stored soil water. Fallow periods <3 months are not expected to change significantly. A greater prevalence of 3-9 month fallows and a decrease in >9 month fallows are expected into the future.

An increase in nutrient (N, P, K and possibly micronutrients) demand will be associated with increased crop production and yields. For N, some of the increased demand can be supplied by an increase in the prevalence of legumes in rotations with cereal crops; however, an increased application of nitrogen-based fertilisers is also likely. The increased supply of P could be met by improving the accessibility of soil P build up through time by previous fertiliser applications or increased P fertiliser application. Demands for K and other nutrients are likely to be met by fertiliser application. Where fertiliser applications increase, the carbon emissions associated with the fertiliser production and application will need to be taken into account in any C balance calculations in order to quantify net benefits. Additionally, any influences that the application of N based fertilisers have on nitrous oxide emissions from soils will also need to be taken into account (see Section 4.5.5)

Table 4-2: Fallow area and fallow management in Queensland *ABS 2003.

Fallow management	2000*	2010	2050
Total area	1.14	1.10	1.10
Fallow <3months	0.14	0.20	0.20
Fallow 3-9 months	0.51	0.70	0.70
Fallow >9 months	0.50	0.20	0.20

4.2.2 Soil carbon stocks - what is potentially attainable?

An indication of the potential increase in soil carbon that may be achievable can be obtained by examining the magnitude of soil carbon loss when agricultural production is initiated. Land use change from native grasslands, woodlands and forests has invariably led to a loss of soil carbon, primarily as CO₂ to the atmosphere. At a global scale, such land use changes have contributed 136 Gt C to the atmosphere since 1850 (Watson *et al.* 2000). For the Australian cropping soils, Dalal and Chan (2001) estimated that 290 Mt C or 1,000 Mt CO₂-e may have been released into the atmosphere in the first 20 years of cereal cropping. For Queensland, soil C stocks have decreased by 30 to 60% since native soil was cleared for cropping about 100 years ago (Wood 1985; Dalal and Mayer 1986; Bridge and Bell 1994). The loss of soil C stock due to land use change from native condition to cropping is estimated to be 42 Mt C or 154 Mt CO₂-e over 20-70 years of cropping. The magnitude of this decrease in soil carbon is similar to the differences estimated by Grace *et al.* (1998) between cropping and pasture soils in the northern grains region (39 Mt C, 143 Mt CO₂-e). Inadvertently, the loss of soil carbon that has occurred through the initiation of cropping has created a potential carbon sink (Table 4-3, Figure 4-3). However, it is unlikely that soil carbon can be returned to its original native values under productive agriculture. Estimates suggest that, under agricultural production systems maximum soil carbon values would equate to 60-75% of that present under native conditions (Lal 1999).

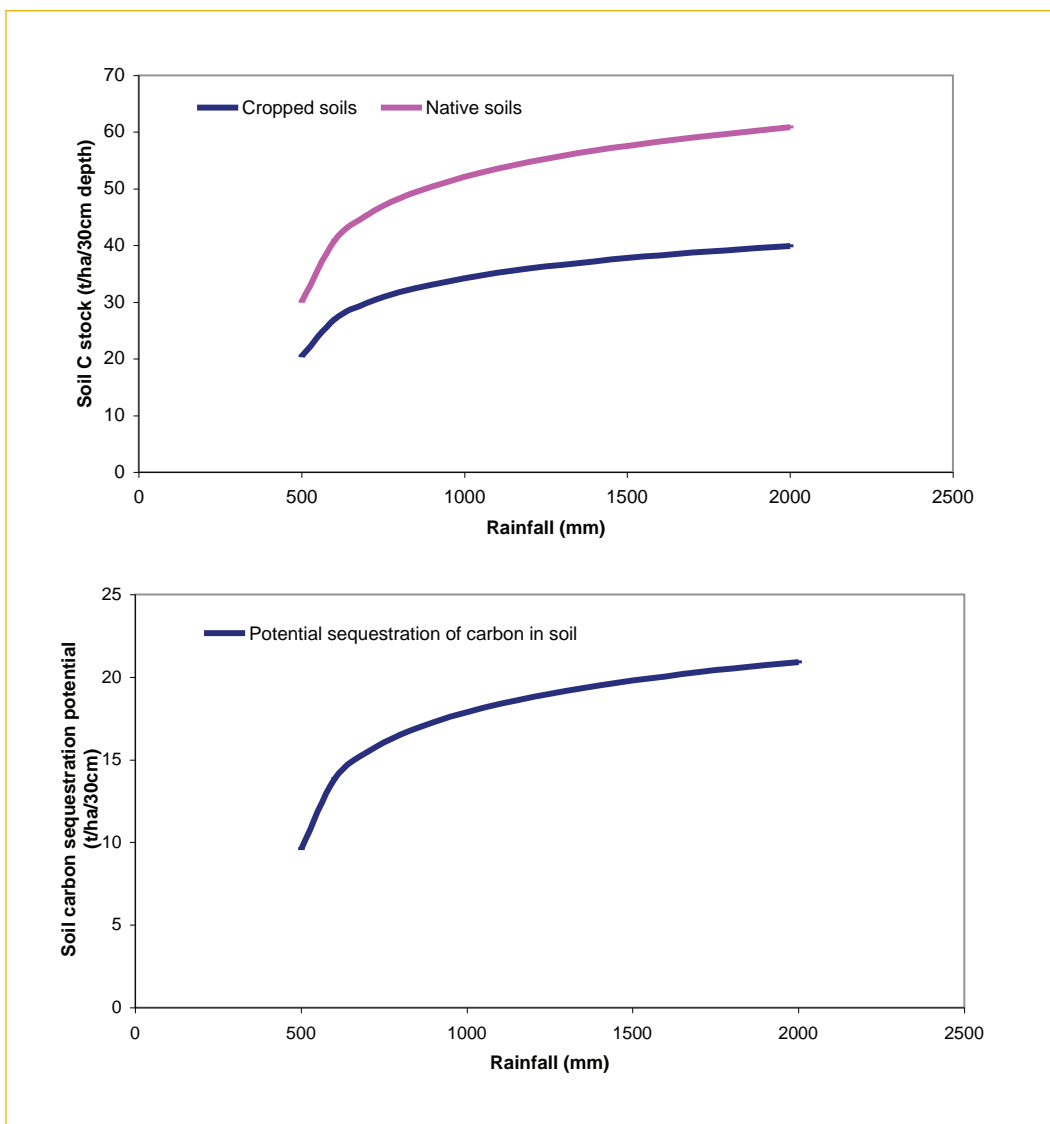


Figure 4-3: Soil carbon stocks in long-term (20-100 years) cropped soils and adjacent native soils as a function of rainfall (top) and soil C sequestration potential as a function of rainfall (Wood 1985; Dalal and Mayer 1986; Bridge and Bell 1994).

Cereal cropping, including cotton, occurs mainly in the 500-800 mm annual rainfall zone and sugarcane occurs mostly in the 800-2000 mm annual rainfall zone. From Figure 4-3, the median soil carbon stock for each of these rainfall zones can be defined (28.5 and 37.5 t C/ha/30 cm depth for the 500-800 and 800-2000 mm rainfall zones, respectively). Under native condition the respective soil carbon stocks are estimated to be 43.1 and 57.2 t C/ha/30 cm depth (Figure 4-3). By multiplying these values by the cropped area in each rainfall zone an estimate of the total soil C stock for cropped soils in Queensland can be obtained (Table 4-3). The difference in total carbon stock between the native condition and cropped soils can then be used to define the potential additional carbon that may be sequestered by Queensland soils in units of either Mt C or Mt CO₂-e (Table 4-3) based on the assumption that soil carbon can be returned to 75% of its value under native condition.

Table 4-3: Soil C stocks in native soils and adjacent cropped soils and consequential potential C sequestration in cropped soils in Queensland assuming that soil carbon can be returned to 75% of that under native condition.

Rainfall range (mm)	Cropped area (m ha)	Soil C stock (Mt C)		Potential soil C sequestration (Mt C)	Potential CO ₂ -e sequestration (Mt CO ₂ -e)
		Native soil	Cropped soil		
500-800	2.2	94.9	62.6	24.2	88
800-2000	0.5	28.6	18.8	7.4	27
Total	2.7	123.5	81.4	31.6	116

4.2.3 Increasing inputs and the duration of carbon storage in soil

The carbon content of a soil results from the balance between carbon inputs and losses. In managed agricultural systems inputs are defined by the amount of carbon captured by growing plants and returned to the soil. Carbon losses are defined by the magnitude of decomposition processes. The rate of carbon addition required to maintain soil carbon content increases in progressing from clay (fine-textured) soils to sandy (coarse-textured) soils (Figure 4-4). This occurs because clay provides better protection to soil C through aggregation and sorption onto mineral surfaces than that available in a sand. For example, a Vertisol containing 50% clay requires a C input >2.2 t C/ha (or 5.5 t/ha of biomass of 40% C) to increase soil C stock. A soil containing 30% clay requires a C input >6.5 t C/ha (or 16 t/ha of biomass, including root biomass). Figure 4-4 also shows that as soil C content increases the rate of C input at any given clay content must also increase to maintain soil C stock at that level otherwise soil C content will decrease. At 40% clay, inputs required for a cropped soil would be >3.8 t C/ha, but for a native soil with a higher carbon content the annual carbon input would increase to >5.6 t C/ha. It is not surprising, therefore, that soil C levels have not increased in many of Australia's agricultural production systems, and indeed may still be decreasing with low C inputs from low yielding crops.

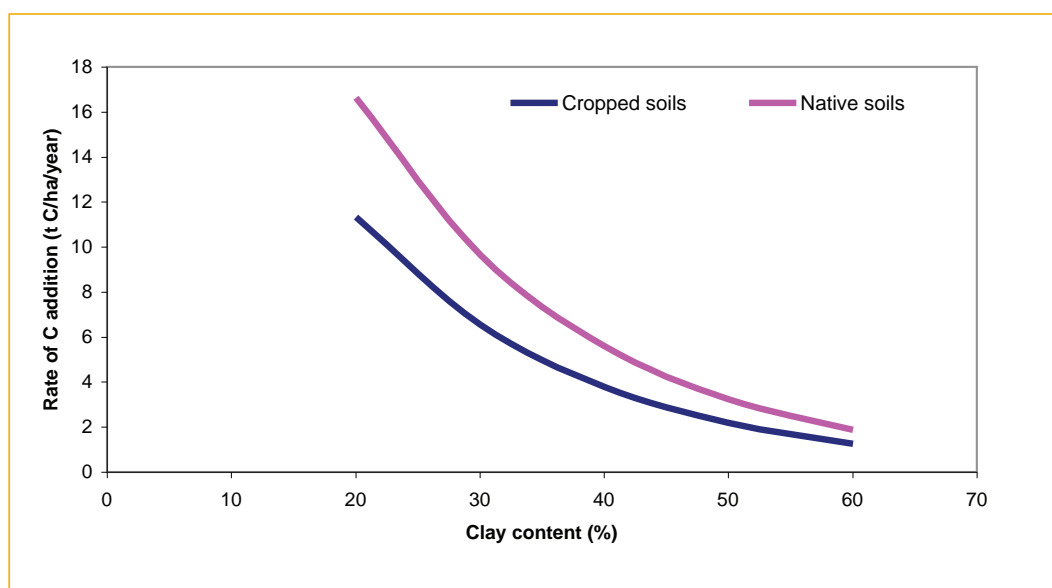


Figure 4-4: Requirement for rate of C addition for soil C maintenance in clay (fine-textured) and sandy (coarse-textured) soils.

4.2.4 Distribution and area under No-till (NT) and minimal till practices under different cropping systems

In the northern hemisphere, NT practices have the potential to reduce the magnitude of annual carbon inputs required to maintain soil carbon values (West and Post 2002). Thomas *et al.* (2007) reviewed the NT practices in grain cropping areas of Queensland over the last 40 years. The NT practice was adopted in Queensland primarily to reduce soil erosion from high intensity rainfalls received during summer. It is estimated that by 2050AD, almost 70% of the cropping area in Queensland will be under NT practice (Figure 4-5). The main hindrances to full adoption of NT practice are soil and stubble-borne plant diseases, herbicide resistant weeds, herbicide residues reducing flexibility in cropping systems especially opportunity cropping, hence the need for strategic minimum till.

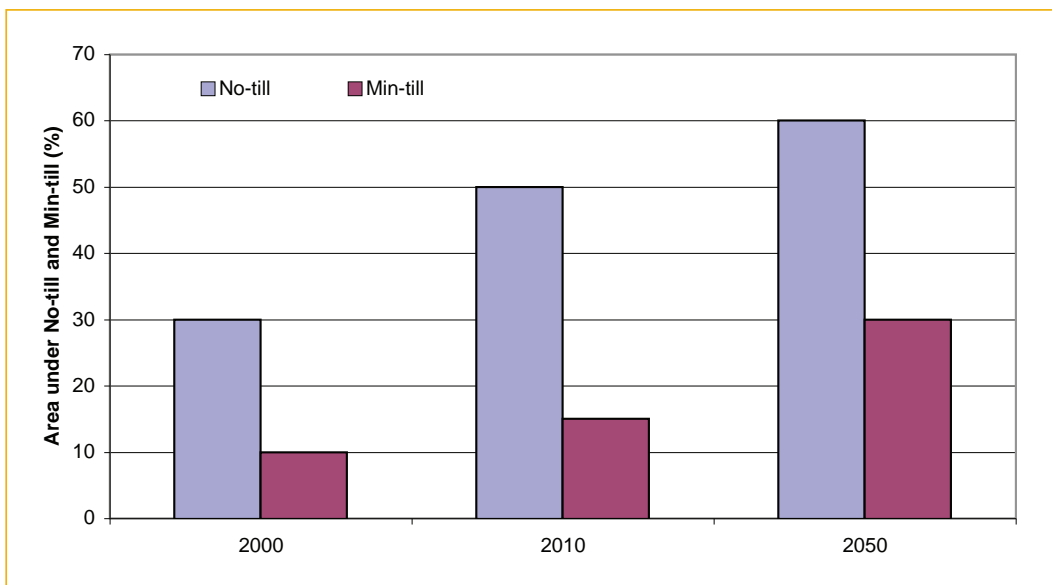


Figure 4-5: Percent cropped area in Queensland under No-till and minimum-till (1 tillage operation during fallow). The 2000AD data are from ABS2003 (0.59 m ha). For 2010AD and 2050AD are estimated from Thomas *et al.* (2007) and Queensland Farming Systems Survey (cited by Thomas *et al.* 2007).

Soil C stocks under NT cropping systems have not increased significantly in a number of cropping systems examined in Queensland (Dalal 1989; Wang and Dalal 2006; Thomas *et al.* 2007; Bell, Moody and Wood, unpublished data, 2009) and elsewhere in Australia (Dalal and Chan 2001; Chan *et al.* 2003; Valzano *et al.* 2005). These results differ from most north American studies where a sequestration of C in soil under NT has been measured (West and Post 2002), although some recent overseas studies concur with the Australian findings (Christopher and Lal 2009). This is explained on the basis that soil C inputs are essentially similar under NT and conventional till practices and often less than the minimum required to maintain soil C content (Figure 3, Liu *et al.* 2009), due primarily to restrictions placed on plant carbon capture by water limitation in semi-arid Australia. A need exists to examine the effect of NT practice on soil C stocks in higher rainfall regions of Queensland.

Differences in soil carbon between conventional tillage and NT practices in four studies conducted in Queensland produced values ranging from -4.6 to 2.2 t C/ha Table 4-4. Based on these data, an estimate of the C stock increase over the 2010 and 2050 period of 2 t C/ha will be used to define the upper limit of carbon sequestration in soil that could be achieved by implementing NT management practices throughout the cropping lands of Queensland. Before completing these calculations it must be recognised that the impact of non-CO₂ greenhouse gases must also be considered, and in particular, nitrous oxide (N₂O) emissions.

Table 4-4: Amount of carbon present in no-till (NT) and conventionally tilled (Con.Till) Hermitage soil in the 0-30 cm depth layer.

	Soil C (t/ha)			CO ₂ -e (t/ha/y)
	Con.Till	NT	Net increase	
Hermitage (13 y) ^A – 0-20cm	39.2	40.7	1.5	0.42
Hermitage (13 y) ^A – 0-30cm	51.5	53.3	1.8	0.5NS
Hermitage (33 y) ^B – 0-20cm	39.8	42.0	2.2	0.24
Billa Billa (9 y) ^C – 0-30cm	32.4	34.6	2.2	0.89NS
Bundaberg (6 y) ^D	37.1	32.5	-4.6	NS
Ingham (6 y) ^D	50.7	48.4	-2.3	NS

A Dalal (1989), Total organic C=WBC/0.88;

B Wang and Dalal (2006);

C Thomas *et al.* (2007), total organic C=WBC/0.88;

D Bell, Moody and Wood (unpublished data)

4.2.5 N₂O emissions under No-till practices and N management under different cropping systems

The depletion of soil C stocks and associated removal of N in agricultural products has depleted soil N fertility. Therefore, a requirement exists to supply additional N fertilizer to crops beyond that typically supplied to maintain growth and ensure adequate agricultural productivity. Estimates of fertiliser N used in 2008 in Queensland are 74,000 t N for cereal production, 74,000 t N for sugarcane, 12,600 t N for cotton, and 13,500 t N for intensive horticulture (Charlie Walker, Incitec-Pivot, personal communication). Thus, average rates of N application are about 60 kg N/ha for cereals, and 120 kg N/ha for sugarcane, cotton and intensive horticulture. Inclusion of a pasture legume phase in rotation with crops reduces N application rates by about 10 kg N/ha for cereals and 20 kg N/ha for sugarcane.

Nitrous oxide is produced naturally in soil by microbial processes involved in soil nitrogen cycling (e.g. nitrification and denitrification). The addition of fertiliser N (inorganic or organic) therefore has the potential to enhance N₂O emissions from soil. Since the global warming potential of N₂O is 298 times that of CO₂ over a 100 year time horizon, it is important to take changes in N₂O emissions into account when assessing the influence of cropping practices on C sequestration in soils. The emission of 7.5 kg N₂O-N from soil will offset the sequestration of 1 t CO₂-C. From 0.7 to 16% of applied inorganic fertiliser N is lost as N₂O from intensive cropping systems. The role of organic N fertilisers in this process requires further investigation. If 100 kg fertiliser N/ha is applied annually in a cropping regime and 1% is emitted as N₂O, about 1 t of carbon would be required to be sequestered in soil each 7.5 years to offset the greenhouse gas emission associated with the use of the fertiliser. If the CO₂ emissions associated with the production, transport and application of the fertiliser N are also considered, the duration over which 1 t of C would need to be sequestered in soil reduces to <4 years.

A recent study of N₂O emissions from non-irrigated cane, pasture and horticultural crops in the high rainfall South-East Queensland region (Grace 2008) indicates emissions of 2.1-4.7% of applied fertiliser N in horticultural crops, and emissions in excess of 5kg/ha for non-fertilised high soil carbon pastures with > 4% carbon in the 0-10 cm soil layer (Table 4-6).

The N₂O emission factors used by Australia's National Greenhouse Gas Inventory for key agricultural systems in Queensland are given in Table 4-5.

Table 4-5: N₂O emission factors (N₂O-N/N applied in kg N/ha) for fertiliser (NGGI 2008).

Agricultural system	Emission factor (%)	IPCC default value or Country specific (CS)	Qld EF (%)	Reference
Non-irrigated crop (wheat and sorghum)	0.3	CS Tier 2	0.5 – 1.1	Wang <i>et al.</i> 2008 Dalal <i>et al.</i> 2008
Sugar cane	1.25	IPCC Tier 1 (1%, IPCC 2006)	0.7 – 2.5*	Weir 1998 Wang <i>et al.</i> 2008 Grace 2008
Cotton	0.5	CS Tier 2	0.7-1.1	Grace 2006 Grace 2007

*Weir (1998), Wang *et al.* (2008), and Denmead *et al.* (2008) have reported values from 10% to 23% in sugarcane soils, one of these soils being acid-sulphate soil.

Table 4-6: Nitrous oxide emissions from horticultural, pasture, cane and rainforest sites in coastal Southeast Queensland.

Site	Study duration (Days)	Cumulative ^B (kg N ₂ O-N/ha)	N ₂ O-N/N applied (%)
Nambour Custard apple	373	2.1	n.d. ^C
Nambour Mango	373	1.7	n.d.
Nambour Pineapple	373	1.2	2.1
Bli Bli Sugar	281	1.4	0.7
Maleny Kikuyu	281	5.5	n.a. ^D
Maleny Rainforest	281	1.3	n.a.
Maleny Macadamia ^A	281	0.9	4.7
Maleny Macadamia ^B	281	0.8	3.9
Landsborough Pasture	281	0.9	n.a.

^A Average value from gas samples collected;

^B Cumulative total based on integration of gas sample data and averaging between days;

^C n.d.- not determined – N application rates during the study period to be determined;

^D n.a. – no application – no N source added during the study.

Under sugarcane, field estimates of N₂O emission factor varied from 1% (non-acid sulphate soils) to >10% (acid sulphate soils). Variation in emission factors across and within land uses can be attributed at least partially to higher fertiliser N rates (~120 kg N/ha for sugarcane versus 60 kg N/ha for cereals), and much wetter conditions due to higher rainfalls in sugarcane regions (800mm - 2000mm) than cereal cropping regions (500 mm – 800 mm). N₂O emissions from horticulture and vegetable crops are similar to those from irrigated crops given in Table 4-7, primarily due to 3-7 times higher rates of fertiliser N use and irrigation when compared to cereal crops Table 4-7.

Estimates of C sequestration in soil managed under No-till practice and fertiliser application are given in Table 4-7. Even under the most optimistic scenario (high carbon sequestration and low N₂O emission), it is apparent that total net greenhouse gas mitigation impact of NT agriculture primarily depends on reducing N₂O emissions from N application Table 4-7. Reduced emissions from No-till versus conventional tillage are mainly due to reduced use of diesel fuel for field operations.

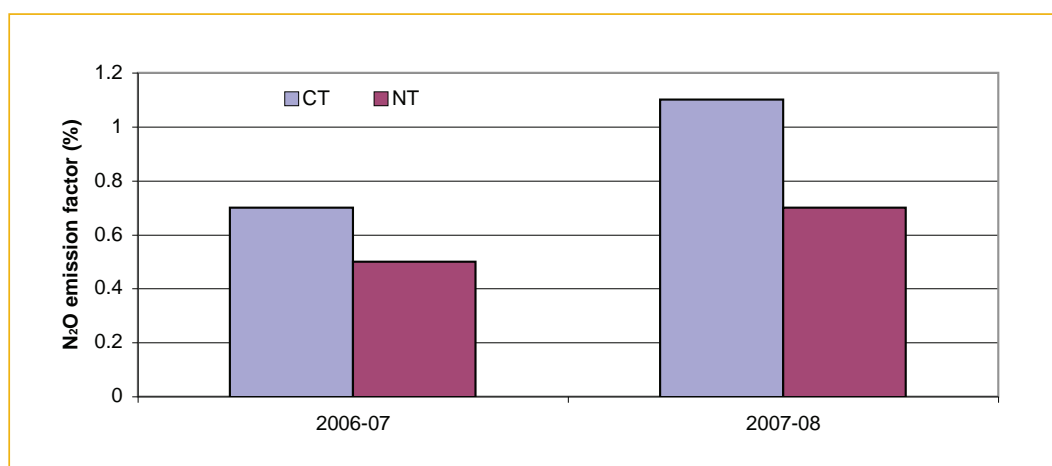


Figure 4-6: N₂O emission factors under No-till and conventional till practices for continuous cereal cropping and 90 kg N/ha fertiliser application at Hermitage, Queensland.

Table 4-7: Net C sequestration potential in Queensland soils managed under No-till with fertiliser applications.

Rainfall range (mm)	Cropped area (M ha)	No-till area 2010-2050 (M ha) ^A	C sequestration (Mt CO ₂ -e) ^B	N ₂ O emissions (Mt CO ₂ -e) ^C	Net GHG Sequestration (Mt CO ₂ -e) ^D
Net increase in No-till area between 2010 and 2050					
500-800	2.2	0.4	-3.23	1.87	-1.35
800-2000	0.5	0.1	-0.81	2.25	1.44
Total	2.7	0.5	-4.04	4.12	0.09
Accounting for all the cropped land under No-till					
500-800	2.2	2.2	-17.75	10.30	-7.44
800-2000	0.5	0.5	-4.03	11.24	7.21
Irrigated	0.2	0.2	-1.61	4.50	2.88
Total	2.9	2.9	-23.39	26.04	2.64

A About 50% of the cropped area is already under No-till

B Assumed 2.2 t C/ha sequestered under no-till (up to 40 years) (Table 4-3)

C N applications of 60 kg N/ha for crops in low rainfall and 120 kg N/ha for crops, mainly sugarcane, in high rainfall range (Charlie Walker 2009, personal communication); the corresponding N₂O emission factors of 0.5 and 1, respectively and GWP of N₂O is 298

D Negative value signifies net GHG sequestration and positive value signifies GHG emission.

4.2.6 Other cropping and pasture-crop systems

Similar principles apply to pasture-crop systems even when fertiliser N application is reduced and pasture phase sequesters C (assuming sequestered C is retained under NT cropping, which is unlikely, Dalal *et al.* 1995; Bell *et al.* 2006). In the pasture phase, moreover, an additional consideration for the total net greenhouse gas account is the emission of CH₄ from animals grazing the pasture, which reduces the C sequestration benefit from pasture substantially Table 4-8.

Table 4-8: Soil C sequestration in soil managed under No-till and fertiliser applications.

Rainfall range (mm)	Cropped area (M ha)	No-till area 2010-2050 (M ha) ^A	C sequestration (Mt CO ₂ -e) ^B	N ₂ O emissions (Mt CO ₂ -e) ^C	Net GHG Sequestration (Mt CO ₂ -e) ^D
Sorghum-sorghum					
500-800	0.5 ^A	0.5	-6.42	3.75	-2.67
Pasture-crop system (20y-20y)					
500-800	0.5	0.5	-18.33	1.17 (6.17) ^E	-17.16 (-12.16) ^E
800-2000	0.1	0.1	-3.67	0.94 (1.94) ^E	-2.73 (-1.73) ^E
Total GHG	1.1	1.1	-28.42	5.62	-22.59 (-16.79) ^E

A Total soil C sequestered from (2010-2050) up to 3.5 t/ha (estimated from David Lester data, 1.5 t C/ha during 17 years of sorghum-sorghum rotation, with fertiliser rate of 80 kg N/ha and 20 kg P/ha).

B Assumed 10 t C/ha sequestered under pasture for up to 20 years (0.5 t C/ha/year measured by Hossain *et al.* 1996 and Dalal *et al.* 1995 in short-term pasture), this is an optimistic C sequestration since C loss in soil in the cropping phase is not allowed for;

C N applications of 50 kg N/ha for grain crops and 100 kg N/ha for other crops including sugarcane; the corresponding N₂O emission factors of 0.5 and 1, respectively and GWP of N₂O is 298;

D Negative value signifies net GHG sequestration and positive value signifies GHG emission;

E CH₄ emissions from grazing animals (0.5 animal (450 kg)/ha/y for 20 years, and 40 kg CH₄ emission/animal, with GWP of CH₄ of 25 (IPCC 2007)).

4.2.7 Improving nitrogen use efficiency and reducing N₂O emissions from fertiliser, legume and soil

Dalal *et al.* (2003) discussed the management options available for reducing N₂O emissions from fertiliser N use in cropping soils. These options attempt to minimise the presence of excess inorganic N within the soil which minimises the potential for N₂O emissions. Management options include:

- Apply fertilizer N at optimum rates by taking into account all N sources available to the crop/pasture from soil (ammonium and nitrate N in the soil at the time of crop sowing, and in-crop N mineralisation), and other N sources such as manure or waste.
- Apply fertilizer N at the rate and time to meet crop/pasture needs and development stage, and when appropriate use split applications.
- Avoid fertilizer N application outside the crop/pasture growing season, and especially prior to a clean fallow period. Avoid fallow periods if season or availability of irrigation permits.

- Monitor crop and test soil for plant available N and adjust fertiliser application rates and timing according to the crop requirement. Ensure water supply to crop/pasture is adequate.
- Apply other nutrients if required so that nutrient supply to the crop/pasture is balanced and N use efficiency is optimised.
- Avoid surface application so that fertilizer N losses are minimised and plant utilisation maximised. Incorporate fertilizer N with soil; apply band placement or point placement close to the plant roots.
- Monitor and adjust fertilizer application equipment to ensure the precision and amount of fertilizer applied, and control over appropriate spatial distribution (Global Positioning System/Geographical Information System) according to the information from yield monitors, crop/pasture monitors (including remote sensing), and soil tests.
- Fertilizers should be in a form (such as granulated) that can be applied evenly, conveniently and cost-effectively. In irrigated agricultural systems, application in sprinkler/drip irrigation may be an effective option.
- Fertilizer may be formulated with urease and/or nitrification inhibitors or physical coatings to synchronise fertilizer N release to that of crop/pasture growth needs so that at any given time minimum amount of mineral N (ammonium and nitrate) is present in soil.
- Practice good crop/pasture management, disease control and good soil management to optimise crop/pasture growth and hence efficient fertilizer N utilisation. Avoid/or reduce cultivation early in the fallow period and retain plant residues to minimise mineralisation and nitrate accumulation during the fallow period.
- Use cover crops to utilise the residual mineral N following N-fertilised main crops or mineral N accumulation following legume-leys. Also, legume-N reduces GHG by reducing fossil fuel and energy use and transport for synthetic fertiliser production.

4.2.8 CH₄ fluxes from soil

Most cropping soils in tropical and subtropical regions provide a small sink for CH₄ uptake (oxidation and consumption), about 1 ± 1 kg CH₄/ha/year. However, soil under arable pasture may provide twice as much CH₄ sink as cropping soils (Dalal *et al.* 2008). However, when compared to potential emissions of CH₄ from livestock, soil uptake is a minor component.

4.3 Potential C sequestration practices for cropped soils

From conventional till to reduced till and no-till. Australian data suggest that in most cropping regions there is similar C input and hence limited or no additional C sequestration (Dalal and Chan 2001). However, it appears that in higher rainfall areas (>550 mm in southern Australia and >700 mm in subtropical Queensland) a potential may exist to increase C sequestration in soil under no-till.

From continuous cropping to ley pastures. Ley pastures, especially grass-legume pasture increases soil C, around 0.5 t C/ha/year or higher, during the pasture phase, but during the cropping phase soil C decreases again. However, the soil C values may still be higher than from continuous cropping. Moreover, there may also be reduction in total GHG emissions from replacement of synthetic N fertiliser (savings from manufacture, transport and CO₂ release from urea hydrolysis).

From cropping to permanent pasture. We have found that land use change from cropping to permanent pasture increases soil C for up to 35 years and may eventually attain C values similar to the soil under native vegetation or even higher if nutrient limitation is also removed (southern Australian experience).

From cropping to afforestation. Increases soil C have been observed but an economic analysis was not found. Aboveground biomass should additionally provide a useful economic product. Emissions Trading Scheme may provide additional incentives.

From ley pasture to permanent pasture. Usually this transition results in increased soil C sequestration.

Use of manures and sources of waste organic materials. Since manures are high in lignin, some manure C is sequestered in a slow pool of soil C and thus resides in soil longer than the labile crop residue C.

Biochar application to soil. Biochar C persists in soil much longer than the crop residue C, and it may have a place in sandy soils to increase CEC and retain fertiliser nutrients but the net GHG benefits requires further analysis.

4.4 Summary

In summary, the attainable CO₂ sequestration by cropped soils is estimated to be 16 Mt CO₂-e for the 2010-2050 period. We consider this estimate as an optimistic scenario. This is approximately 14% of the C sequestration potential in cropped soils (116 Mt CO₂-e over 2.7 M ha, Table 4-3), which can be utilised under current cropping systems. Apparently, a large shift in farming systems is required if most of the C sequestration potential is to be realised (land use change from annual to perennial cropping/pasture, and afforestation, etc., which is not considered here).

4.5 Defining Uncertainty

Uncertainty in estimating soil C stocks (due to spatial heterogeneity) and temporal variation over time due to rainfall variability is currently difficult. In most instances, it is likely to exceed >20%, which may be larger than the changes in C stock over 5-10 years (<20%). Climate change, especially increasing temperatures and reducing rainfall may impact adversely on soil carbon. On the other hand, increasing CO₂ fertilisation and atmospheric N deposition may increase plant biomass and therefore plant C input to soil.

4.6 Risk and Barriers to Implementation

Risk to implementation of emission trading arises from the uncertainty and costs in measurement of soil C stocks at the project level. The cost of estimating C stocks may be reduced by the use of modelling and ground truthing at key monitoring sites, and rapid methods of measuring using either remote sensing or visible-near infrared spectroscopy (VISNIRS) *in situ* or mid-infrared spectroscopy (MIR) in the laboratory. Eventually, however, projects will need to be aggregated based on an approved management practice, which can be audited rapidly and at low cost.

Barriers to implementation are the lack of approved management practices for emission trading for Queensland cropping systems. For example, NT practice can not be used for most Queensland regions unlike that for north-east America on Chicago Carbon Exchange. This is hindered by costs of establishing the baseline, monitoring and auditing on a project and regional scale.

4.7 Compliance and Auditing

Increasing use of robust models to estimate C stocks and N₂O emissions and CH₄ fluxes is essential to increase compliance and auditing. However, current models need to be calibrated and verified against the measured data for different cropping systems and regions. Therefore, significant research effort is required to effectively measure emissions and to populate models with verifiable data. One option currently considered is to audit a carbon pollution reduction scheme for fertiliser supply. This may provide incentives to growers to optimise N use by a mix of N sources (fertiliser, legume, and organics). However, auditing at the farm gate with current technology is cost prohibitive.

4.8 Other Benefits and Consequences

Sequestration of carbon in soils brings a number of benefits, including increase in soil organic matter, which improves soil physical, chemical and biological functions. Soil organic matter is critical in soil aggregation. It increases infiltration, reduces bulk density, retains nutrients against leaching, retains herbicides and pesticides for microbial degradation rather than polluting water bodies, and among other benefits, it reduces erosion and therefore sediment and soil loss, and it increases microbial biodiversity. Therefore, sequestration of soil carbon is a win-win situation both for GHG mitigation and natural resource improvements.

4.9 Lateral Thinking

Even if carbon sequestration in cropping soils plays a smaller role in a Carbon Pollution Reduction Scheme than forestry, its multiple benefits allows us to recommend management practices which lead to carbon sequestration in soil, provided these practices also enhance and ensure food and fibre supply to the community. Eventually, food and fibre supply systems based on perennial crops, grasses, legumes (less reliance on fertiliser N) and trees should be developed for cropped lands of Queensland. Water supply is the major limitation to enhanced C input in the 500-800 mm grains cropping regions and nitrogen is the major limitation in the 800-2000 mm rainfall regions, although optimum utilisation of both water and nitrogen (and other nutrients as well as disease if limiting production) will be required.

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4.10 Research Groups

State level

- Queensland Department of Environment and Resource Management
- Queensland Department of Employment, Economic Development and Innovation
- CSIRO Sustainable Ecosystems
- BSES, Queensland

Universities

- UQ, QUT, Griffith, CQU, USQ, JCU

Australia

- CSIRO Land and Water
- CSIRO Sustainable Ecosystems
- State Government Agencies

International

- Ecology Lab, Fort Collins, USA
- Carbon Sequestration group (CW Rice *et al.* Kansas, USA)
- Carbon Management and Sequestration Centre, Ohio State University, USA
- Euro-Net for soil carbon and N₂O, EU, Europe
- Soil Carbon Management groups (India, China, Japan, and other countries)

4.11 Research Activity and Focus

- Assessment of soil carbon stocks and changes under different management systems
- Soil carbon distribution, aggregation, chemistry and pools
- Soil carbon modelling
- Assessment of N₂O emissions and regulations
- N₂O modelling
- Quantification of net CH₄ emissions

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Table 4-9: Methodology for estimating potential, attainable and base greenhouse gas sequestration/mitigation for soil carbon.

Option	Build soil carbon storage and mitigate N ₂ O emissions for agricultural land	
Current or Business as Usual Net Carbon Storage (Mt CO ₂ -e) from 2010 to 2050	Nil Agricultural soils are not included in NGGI except for fertiliser N and soil disturbance (net emission of 4.5 Mt CO ₂ -e/year for Queensland in 2006)	
Net Potential* Carbon Storage (Mt CO ₂ -e) from 2010 to 2050	Australia	1, 000 Mt over 40 years 25 Mt/yr
	Queensland	154 Mt over 40 years 4 Mt/yr
Functional Unit and Basic Algorithm Used to Calculate per Unit CO ₂ -e	Potential soil carbon sink created by soil carbon loss from annual cropping	
Scaling Up Process	Two zones were used: Grain cropped area in 500-800 mm rainfall, 2.2 M ha Sugarcane and intensive horticulture in 800-2000 mm rainfall, 0.5 and 0.1 M ha, respectively	
Attainable* Net Carbon Storage (Mt CO ₂ -e) and factors driving this translation	Queensland	Most of the potential C sink is unlikely to be attainable in annual grain cropping, and intensive industries. Potential C sink requires nitrogen inputs, which means N ₂ O emissions. In most systems N ₂ O emissions exceed soil C sequestration. However, N inputs are required to increase C input from productivity gains. Therefore, N use efficiency is critical in realising most of the C storage potential. This is also linked to enhanced water use efficiency. Therefore, efficient nitrogen and water use requires perennial cropping and perennial grass and tree cropping systems. High C input crops such as high yielding sorghum-sorghum rotation and pasture-crop rotation and tempered by N ₂ O emission from fertilisers and CH ₄ emissions from grazing animals. The likely C storage is estimated to be 16 Mt CO ₂ -e during 2010-2050 period or 0.4 Mt/yr.

* See Chapter 1 Section 1.2 Methodology for explanation of potential, attainable and base.

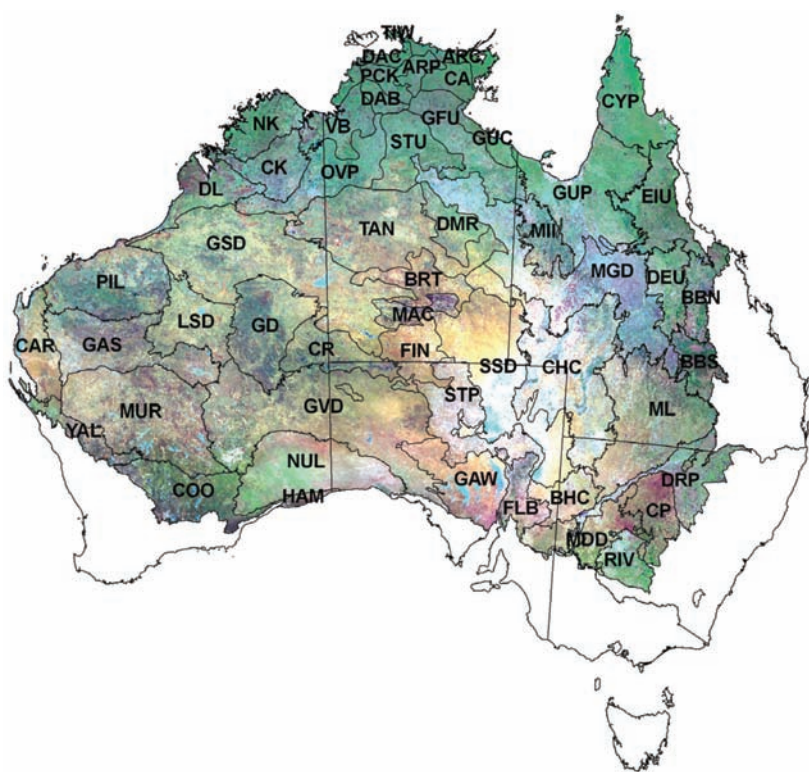
5 Rehabilitate overgrazed rangelands, restoring soil and vegetation carbon-balance

Roger Gifford and John McIvor

5.1 Definition and Scope

In this Chapter we evaluate the technical potential for sequestering C into Australian grazed rangelands, and management options for achieving increased C storage, for purposes of greenhouse gas mitigation using a market-based approach. For the purposes of this report rangelands, including savannas, are regarded as extensive permanent grazing lands, largely of native vegetation (but sometimes including sown species such as buffel grass) that are grazed by domestic stock principally cattle and sheep. Rangelands cover 81% of Australia (Figure 5-1) but large areas in the arid interior are not grazed. Such lands lie in both tropical and temperate zones of Australia. The mulga lands (i.e. where mulga dominates or contributes significantly to the biomass) are one component of these rangelands and occur in a band across central Australia from south-west Queensland to near the Indian Ocean.

Figure 5-1: Extent of the Australian rangelands (from Bastin et al. 2008).



Two options from Table 22.2 of the Garnaut Review (“Removal by soil – high volume grazing land” and “Restoration of mulga country”) have been here combined as mulga lands are a component of the overall rangelands, and the potential gain in both cases is from the removal of greenhouse gases by altered land management. For the rangelands as a whole this is by “changed practices to rehabilitate previously degraded rangelands” and for the mulga lands it is by “comprehensive restoration of degraded, low value grazing country”. There appears to be some confusion in the Garnaut Review as to whether the two options are separate (they are listed separately in Table 22.2) or the mulga lands are included in the rangelands (Box 22.2).

The Garnaut Review (Table 22.2) estimated that rehabilitating Australian permanent grazing land, which is largely

temperate and tropical rangeland, could sequester into soil carbon 286 Mt CO₂-e per year for 20-50 years. For the mulga lands, the potential was estimated to be 250 Mt CO₂-e per year for several decades by restoration of these degraded lands.

No details are provided in the Garnaut Review of how the value was calculated for the mulga lands but the overall rangeland value is based on the adoption, on all the assumed 358 M ha of such land, of certain reduced-intensity grazing practices that are recommended by the Chicago Climate Exchange (CCX) for the rehabilitation of degraded US rangelands. The grazing practices recommended by the CCX for building soil C stocks on rangelands are:

"Project involves rangeland management practices that include use of all of the following tools through the adoption of a formal grazing plan:

- a. Light or Moderate Stocking rates;
- b. Sustainable Livestock Distribution which includes:
 - i. Rotational grazing
 - ii. Seasonal use."

(http://www.chicagoclimatex.com/docs/offsets/CCX_Rulebook_Chapter09_OffsetsAndEarlyActionCredits.pdf#page=142)

We address such questions as:

- Are these CCX management recommendations actually appropriate for rangeland soils in Queensland and Australia?
- Are all Australian rangelands "degraded", in a sense that reduced, and rotational and seasonal grazing could improve their condition, as is implicitly assumed by the Garnaut Report calculation?
- Are rangelands classifiable as either degraded or not degraded and how do we distinguish one from the other?
- Do "degraded" rangelands necessarily have lower whole-ecosystem C stocks?
- What management options exist to reduce the net emissions of greenhouse gases from managed Australian rangeland ecosystems?

5.1.1 Whole ecosystem Carbon Stocks

An immediate observation on the Garnaut calculations based on Chicago Climate Exchange rules is that they do not provide for rangeland soil C trading where rainfall is less than 355 mm yr⁻¹ (14"). As a large fraction of Australian rangelands have less than 355 mm rainfall, it seems that the Garnaut estimate may have been applied to too large an area in terms of the CCX rules.

Although using the rangelands to sequester C is frequently discussed in terms of building up soil C stocks, net emissions of GHGs from the whole grazed ecosystem is more relevant than accumulation of soil C alone, for several reasons:

- 1) Grazing by ruminants involves methane emissions. The rate of release of methane per ha varies with stocking rate and vegetation quality, both of which can influence soil C stocks (methane emissions are addressed by others in this document), while soil processes oxidise atmospheric methane and release nitrous oxide.
- 2) Gains or losses of soil C can be accompanied or countered (depending on the ecosystem and the management option involved) by changes in above-ground C stocks.
- 3) Management of Queensland rangelands includes not only grazing pressure but also fire and woody plant growth (and clearing and regrowth after clearing) both of which have repercussions for ecosystem C stocks and soil C stocks. Also bearing on the interactions between stocking rate, woody plant growth and fire occurrence, is the episodic nature of runs of dry years (Fensham and Holman 1999) and runs of wet years in Australian rangelands which influence pasture condition, soil C stocks, plant recruitment, establishment, and death, and grazing intensity decisions by graziers.

Given the above, grazing management is not the only option for increasing soil and total ecosystem C stocks on the rangelands. Other options are woody plant management and fire management. However, purposefully altering the fire regime by, for example, frequent low intensity burns to replace occasional intense wildfire, alters many GHG related things such as total soil C, long-lived soil char, above ground woody biomass, and combustion-related GHG emissions (carbon dioxide, carbon monoxide, methane, non-methane hydrocarbons, atmospheric soot, ozone and oxides of nitrogen etc). Quantification of the soil C repercussions of fire management is complicated, fraught with uncertainty and has been little researched. While the less frequent the fires the more soil C stocks in tropical savannas accumulate (Bird *et al.* 2000), the soil-C benefits of complete fire suppression will nearly always eventually be at least partly undone by the occasional massive unsuppressed intense wildfire event. Thus frequent controlled low intensity managed-burns at the beginning of the dry season or end of the wet season may represent a carbon-accumulation management strategy. In some environments, notably in the moister areas, mineral fertilisation (especially P and S) and seed sowing (especially forage legumes) of pastures are powerful options for increasing ecosystem C stocks which may also suffer counter-effects via other GHG emissions like nitrous oxide.

Mulga lands are a subset of rangelands for which the relationship between grazing and the woody component of the grazed ecosystem is different because the mulga trees can be cut or knocked over to provide drought feed for grazing animals. The mulga re-grows readily.

5.1.2 Approximate size of Australian rangeland C-stocks

There is no continent-wide or State-wide compilation of measured C stocks above- or below-ground for Australia because the measured data are so few. Indeed the stated area of rangeland varies between authors. Based on broad-brush information and assumptions in the international literature Gifford *et al.* (1992) estimated that the Australian rangelands, occupying some 500 million ha, contain about 34Gt C in soil (depth unspecified) and 17 Gt C live plant biomass (Table 5-1).

Table 5-1: An approximate estimate of the C stocks in plant (above ground) and soil of Australian rangelands. Gifford et al. (1992) based on Olson et al. (1985) and other information.

Ecosystem Type	Area (x10 ⁶ ha)	Live C (Gt)	Soil C (Gt)
Dry wood/scrub/grass complex	164	4.92	12.31
Dry tropical/subtropical woodland	82	4.90	9.78
Semi-arid woodland	74	2.97	5.94
Hot grass shrub complex	125	1.13	2.26
Second growth wood/field mosaic	27	1.11	1.11
Interrupted fields/woods	3	0.61	0.61
Mediterranean woods/shrub/grass	18	0.53	1.36
Tropical savanna/woodland	17	0.50	1.00
TOTAL	510	16.7	34.4

Another estimate (though without details) for the Australian rangeland soil is 48 Gt C (to a depth of 1m) (Baker *et al.* 2000). However, as with Australian continental net primary production estimates, which vary 5-fold (Roxburgh *et al.* 2004), above- and below-ground carbon stocks in Australian rangelands could differ substantially – perhaps by a factor of 2 from the above 34-48 Gt range. Measured soil carbon data for some specific rangeland areas of Queensland are now coming available (Bray *et al.* 2006, Harms and Dalal 2003).

Adopting, for heuristic purposes, a rounded figure of 40 Gt C in Australian rangeland soils, the Garnaut estimate of sequestration potential into Australian rangeland soils of 286 Mt CO₂ yr⁻¹ (78 Mt C yr⁻¹) would amount to a rate of increase of about 0.2% yr⁻¹, totalling 8% if sustained over 40 years. Expressed in absolute amounts, a carbon stock of 40 Gt C in the 510 M ha of Table 5-1 averages 78 t C ha⁻¹. This figure seems rather high for most of the tropical rangelands even if considered down to 1m depth. For Queensland rangelands alone, an analysis by Barrett (personal communication) using the VAST 1.2 system, found a mean C-stock density down to 1m of 60 t C ha⁻¹. The Garnaut estimate of an increase of 78 Mt C yr⁻¹ equates to an average of 217 kg C ha⁻¹ yr⁻¹ over the area of 358 M ha assessed. There are few data available on rates of carbon change under Australian pastures, but Gifford *et al.* (1992) found that 3 studies on the rates of soil C increase in pastures subject to “pasture improvement” (i.e. P and S fertilisation and introduced fodder legumes) averaged about 500 kg C ha⁻¹ yr⁻¹. Thus while 150 kg C increase may seem reasonable compared with 500 kg C yr⁻¹, the latter increase is very much dependent on the inputs of mineral nutrients and the associated leguminous N-fixation in relatively high rainfall environments. It was not an expression of relaxation of grazing. On the contrary, fodder grazing would have increased under the fertilised treatment.

5.1.3 The impact of rangeland grazing in Australia and Queensland on soil degradation

There is little experimental data published on the impact of grazing pressure on soil C stocks. Using three mainline scientific literature search engines, Conant and Paustian (2002) conducted a global literature search and analysis to evaluate the influence of overgrazing on soil C stocks per m². After filtering the relevant papers for certain data inadequacies for the task, they identified only 22 data points globally comparing soil C stocks under moderate and heavy grazing. Of these one was in Australia (in the Bogong High Plains of Victoria). There were no studies found anywhere examining the effect of a changed grazing intensity from overgrazed to moderate grazing for given plots.

Other work does exist but may not fit the necessary criteria for the Conant and Paustian type of meta-analysis. For example, the soil sampling depth may be too shallow such as just the top 75mm used by Northup *et al.* (1999) and Northup *et al.* (2005), who studied the effect of grazing pressure on the soil and litter C around grass tussocks in dry eucalypt woodlands in northern Australia that had different levels of vegetation deterioration. That study found that degraded plots, which were also heavily grazed, had only 53% as much C in the top 75mm as the non-degraded plots that were also receiving no grazing. Heavy grazing of the non-degraded plots reduced soil C% in the top 75mm by 20% compared with light grazing of such plots. An earlier experimental study of the

effect of grazing pressure on soil C in the Charters Towers area of semi-arid north Queensland (Holt 1997) reported that 6 to 8 years of heavy grazing at 5x the stocking rate of a pasture grazed at a pressure that was just slightly lighter than the average for the region, had not altered the soil carbon concentration despite reduction in soil microbial biomass C (representing 4% or less of total soil C). Thus as in the world data, results of the few grazing pressure studies on soil C in Australian rangeland pastures give a mixed conclusion. But it is clear that any soil C change as a result of change in grazing pressure takes many years to be detectable.

The definition of "degradation" varies with author. No explicit agreed definition has emerged. The extent of soil degradation through overgrazing, anywhere in the world, has relied not on actual sampled data linked to a quantitative definition but on local or regional expert subjective opinion of the state of deterioration (Conant and Paustian 2002). Globally such local expert opinion on degradation was compiled by a GLASOD (Global Assessment of Soil Degradation – International Soil Reference and Information Centre) Survey (Oldeman et al. 1990, Oldeman 1994, and <ftp://ftp.fao.org/agl/agll/docs/landdegradationassessment.doc>). In Queensland such a compilation of local opinion was also made by Tothill and Gillies (1992). These two compilations give divergent estimates of the area of grassland that is thought by local experts to be degraded in Australia. Conant and Paustian (2002) calculated from the GLASOD survey of the 1990s that 11.2% (49.1 M ha) of the 437 M ha of grassland in the Australia/Pacific (predominantly Australia) region was overgrazed. Ash et al. (1995) summarised the opinion-survey conducted by Tothill and Gillies (1992) for 143 Mha of important grazing lands in northern Australia covering Queensland, the Northern Territory and Western Australia. The survey found that 30% of these lands had deteriorated somewhat and 9% were severely degraded.

For Queensland alone, the Tothill and Gillies (1992) compilation is summarized in Table 5-2. It indicates that 41 % of Queensland rangeland pastures were considered deteriorated around 1990 but could be recovered with improved management and normal rainfall, while 17% were degraded beyond recovery without high expenditure and complete land use change. Tothill and Gillies (1992) also estimated that in the mulga pasture land 51% was in a deteriorating condition and 29% was in a degraded state. It is probably not in fact feasible, in practice, to rehabilitate the degraded lands by 2050, so the estimates below are based on changed management of the deteriorating lands.

An earlier assessment for Australia in 1975 (Australia 1978) was summarised by Woods (1983). That study indicated that of 336 M ha of grazed arid rangeland in Australia 55% was affected to some degree by vegetation or soil deterioration. The fraction in the substantial degradation category was 13% (43.2 Mha) of the pastoral land in the arid zone (8% of the total arid zone).

However, "overgrazing" and "deterioration" and "degradation" are all subjective terms with different nuances of meaning that are not explicitly defined. "Overgrazing" and "degradation" are certainly not synonyms. Sometimes degradation is implicitly referring to the soil condition, sometimes to the vegetation condition. There are many forms of degradation such as soil erosion of various types, soil compaction, soil acidification, salinisation, undesirable change in herbaceous species composition (e.g. annual grasses replacing perennials), loss of plant cover; woody plant thickening, weed invasion and loss of biodiversity, each with different implications for soil carbon stocks. Notes alongside the individual entries that are summed in Table 5-2 indicated woody thickening was a dominant form of deterioration in Queensland. But the fraction of the area that is designated in Class B or C that is suffering gain of woody plant cover as opposed to loss of forage plant cover and gain of bare ground is not indicated. This distinction is important in terms of whether the rangeland has increased or decreased carbon stocks as a result of the deterioration and degradation defined from the perspective of suitability for productive grazing. For 60Mha of grazed woodlands in Queensland, Burrows et al. (2002) showed that the mean rate of increase of above ground biomass by woody thickening was 530 kg C ha⁻¹ yr⁻¹ from which they estimated that the total above and below ground increase in all grazed woodlands of Queensland could be about 35 Mt C yr⁻¹.

Currently parts of Queensland are being assessed for grazing-land condition on a new four-point scale from good (A), to very poor (D) using rapid assessment (i.e. drive-by visual assessment) and satellite imaging approaches (Beutel, T, pers. communication). This condition description is intended to express a potential of the land to produce useful forage and does not necessarily have a simple or consistent correlation with ecosystem C-stocks. It is possible for grass cover to increase while whole ecosystem and soil C-stocks decrease. The task of evaluating the grazing land condition and ecosystem C stocks of the entire State of Queensland is a major one with 250 grazing land types now being distinguished.

Table 5-2: The area and fraction of Queensland pastures in each of three classes of degradation (A = no significant deterioration, B = deteriorated, C = severely degraded). The assignment to classes A, B or C was the subjective judgments of local experts. (Data derived from Tothill and Gillies, 1992, Table 3a).

Pasture type	Area ('000ha)	Area in class (Mha)			Fraction in class		
		A	B	C	A	B	C
Plume sorghum	928	835	46	46	0.90	0.05	0.05
Schizachyrium	8663	1900	5729	1035	0.22	0.66	0.12
Former rainforest	862	345	431	86	0.40	0.50	0.10
Bladygrass	1994	326	1253	415	0.16	0.63	0.21
Black Speargrass	22896	7167	11986	3743	0.31	0.52	0.16
Ribbongrass	632	600	32	0	0.95	0.05	0.00
Aristida/Bothriochloa	31897	15923	10381	5593	0.50	0.33	0.18
Seasonal riverine plains	5425	2170	2170	1085	0.40	0.40	0.20
Brigalow pastures	8509	3430	3156	1923	0.40	0.37	0.23
Gidgee pastures	2684	939	866	879	0.35	0.32	0.33
Qld Bluegrass	2372	617	854	901	0.26	0.36	0.38
Bluegrass-Browntop	4957	991	3718	248	0.20	0.75	0.05
Mitchell grass	29833	17128	9977	2728	0.57	0.33	0.09
Spinifex	19177	9927	6631	2619	0.52	0.35	0.14
Mulga	18358	3672	9355	5331	0.20	0.51	0.29
Georgina Gidgee	1599	1119	320	160	0.70	0.20	0.10
Saltwater couch	802	722	40	40	0.90	0.05	0.05
Total	161588	67811	66945	26832	0.42	0.41	0.17

5.1.5 The ecology of the rangeland carbon cycle

Australian rangelands usually comprise an interacting mixture of annual (often undesirable to the grazer) and perennial (mostly desirable) grasses and herbs, frequently containing dispersed woody shrubs and trees. Landsat imagery on a 30m resolution indicates that, for about a half of Queensland rangelands, woody plants are at a density sufficient (> about 10% projected canopy cover) for the ecosystem to be described as "woodland" where they contribute a large fraction of the ecosystem's C stock (Queensland Government 2008). The prevalence of woody, annual grass and perennial grass components varies through time as well as in space both by natural dynamics and via management. The carbon stocks of the ecosystem increase with the woody plant content, and decrease with the annual species content compared with perennial grasses. The high carbon stocks of woody ecosystems are primarily because woody stems contain a lot of long-lived carbon per hectare compared with pasture species. Secondly, it is also because the soil profile to depth may contain more organic matter in a wooded system than a comparable grassy ecosystem (such as the rangelands of central Queensland, Harms *et al.* 2005).

In the tropical rangelands such as those of Queensland, the woody component (where there is a woody component) often tends to increase with time under domestic stock grazing (Burrows 2002) until the thickening woody component is re-cleared. It is thought that thickening occurs because grazing removes grassy fuel and hence reduces the frequency of wildfire that kills young establishing seedlings of some woody species (McKeon *et al.* 2009). Many woody species are also unpalatable to domesticated stock. Thus overgrazing of tropical grassland often, but not always, produces woody-species thickening (Gifford and Howden 2001). This may not be true of mulga-dominated (*Acacia aneura*) rangelands where removal of grazing can increase woody density as long as wild fire can be suppressed (Moore *et al.* 2001, Howden *et al.* 2001). However, although fire may be successfully suppressed for many years, there inevitably comes a time when an intense wild fire event based on the high accumulated woody fuel density wipes out much of C-stock gains derived from fire suppression. Thus, management to reduce overgrazing can either reduce or increase carbon stocks of rangelands depending on the response of the woody species involved to grazing and the wildfire regime that eventuates from attempted regular fire suppression.

5.1.6 Dynamics of rangeland C-cycle

Rangelands behave as complex adaptive systems whose inherent complexity is not amenable to simplification (Walker and Abel 2002). They are in a continuous state of change on all timescales. Any one patch experiences transition through phases of build-up (accumulating the environmental resources available including accumulation of C stocks) followed by a “mature” state (conservation of the garnered resources such as carbon), and then at some stage collapse from a disturbance such as a “clearing” event, a period of overgrazing, wildfire, major drought or flood. This collapse releases resources to the atmosphere, elsewhere in the landscape, or the ocean (such as the accumulated C released as CO₂), and is followed by reorganisation leading to starting the cycle over again with resource recovery. In the highly variable climate of Australia a high rainfall series of years or decades can drive the accumulation phase, a major drought or low prices for animal products inhibiting stock sales can drive the collapse stage (McKeon *et al.* 2004), and more average climate conditions in-between permits a “marking time” period of gradual system reorganisation that positions it to respond to the next wet period (McKeon *et al.* 2004, Stafford Smith *et al.* 2007). At certain points in this cycle a rangeland may be regarded as “degraded”. This adaptive cycle may occur over years, decades or even centuries on any one patch. As is amplified below, the net carbon gain by an ecosystem can be positive or negative in any one year depending on seasonal weather as well as on management and the occurrence of episodic disturbance events. Even 5 year periods can show substantial losses or gains of soil C from rainfall variability (Hill *et al.* 2006). The seasonal swings between net C-uptake and net C-release are much larger than the multi-year trend-line of accrual of carbon in-between episodic major disturbance events.

Ecosystem C stocks are “turning over” all the time – continuous C inputs from plant growth and associated plant-litter deposition are offset by C losses from soil organic matter decomposition, grazing with removal of stock and products for sale, and fire. In any one year the increase in C stock (i.e. net sequestration) is the small difference between large inputs and large losses. Some years it may be positive, in others negative. In many tropical rangelands worldwide, the woody component tends to increase over time. As the woody component increases, the standing stock of carbon above ground increases (Burrows *et al.* 2002) and the productivity of grasses and hence of grazing animals decreases (Burrows 2002). The soil carbon stock in the whole soil profile to depth usually increases while trees are thickening because of the deep rooting of trees and the greater resistance of woody roots and dead aboveground woody material to decay. However, the soil carbon stock in the top 300mm, which may be the one subject to a C-trading and compliance scheme, may decrease because of the decline in density of the shallower rooting grasses as trees thicken.

Thus, increasing the carbon stocks in a rangeland by a changed management regime is not like filling up a tank with inert charcoal and then leaving it as a sequestered repository. It is more like increasing the water level in a leaky tank that has a continuous but variable inflow of water from a tap and a leak rate that varies also. For a managed increase in the level of ecosystem-carbon (like the amount of water in the tank) to be sustained at a constant level, continual ongoing management of the balance between C inputs and C losses is required. Thus the costs of increasing the C level, perhaps remunerated by some financial scheme payments, require the factoring in of a permanent commitment to continuing management to hold that carbon stock at the elevated level by continually adjusting both the input flow and the leaks. For GHG mitigation policy to be effective there must be a plan for permanent remuneration of the future land-managers to maintain the C-elevating management strategy. There will need to be some sort of strategy in the trading scheme to accommodate the inevitable major losses of sequestered C from unplanned episodic disturbances from time to time. Using sequestered-C insurance schemes to deal with this may not be attractive to insurance companies because the accumulated C loss phase is a certainty sometime in the future for most rangelands as part of the system behaviour and very expensive to quantify especially when soil is stripped off the surface in some places possibly accumulating elsewhere (such as a water reservoir) or washing out to sea where it may oxidise to CO₂ at a different rate (slower or faster) than it would have in the soil.

There are several requirements for evaluating whether a patch of grazed rangeland can be cost-effectively managed to verifiably sequester carbon and to retain that carbon:

- 1) What baseline year (or period) for defining change is required for the scheme and are the carbon stocks above-ground and below-ground known? If the baseline year is in the past can these stocks be determined?
- 2) Is it known whether the baseline year (or period) has followed years in which weather conditions, disturbance events and grazing history were conducive to average, above-average or below-average ecosystem carbon stocks for that site at that time?
- 3) Is it known how to quantify and “factor out” future fluctuations in ecosystem carbon stocks that are attributable to causes, such as runs of low or high rainfall years, gradually increasing atmospheric CO₂ concentration, and changed climate that are not attributable to the purposeful management options adopted? What philosophy is to be adopted for dealing with windfall gains and losses in a C-trading scheme?
- 4) What management techniques could be used that would ensure that ecosystem carbon stocks increase and stay high over centuries?
- 5) What technique is to be used that is location specific and sensitive enough to detect and verify that the modelled increase (i.e. predicted, expected, claimed or nominally deemed) in C-stock has actually occurred and is maintained after the period of managed net sequestration has saturated?

6) What is the cost, explicit and implicit (i.e. opportunity costs), of the management and verification techniques for increasing the stock of ecosystem C compared with the payments made for C-sequestered? In general, one would expect that, in the absence of contrary evidence on any particular site, cash returns from grazing would decrease with increasing emissions reduction (Moore *et al.* 2001, Howden *et al.* 2003, Northup *et al.* 2005). In reducing stocking intensity, there comes a point at which grazing becomes unviable. After the impact of the technique employed for increasing soil C stocks has saturated, what are the ongoing annual costs of maintaining and verifying that elevated level of ecosystem C? Who pays those costs or for the carbon re-emitted to atmosphere if non-managed events (e.g. flood or fire) cause a C release event?

From the above, there are a number of reasons why it is clearly not at present possible to make an accurate assessment of the potential for sequestering C into Australian rangeland ecosystems. These reasons include the lack of accurate baseline data on stocks, and variability in the response of above-ground and below-ground C-stock to alternative grazing, burning and clearing strategies. For instance, modelling results of Harper *et al.* (2007) showed that *partial* (50%) destocking of the West Australian rangelands still involved reducing ecosystem C stocks but *full* (100%) destocking did allow increased ecosystem C-stocks.

To consider the type of management that would foster an increase of whole ecosystem carbon stocks it may be helpful to distinguish three types of rangeland in Australia. The first is rangeland that is naturally grassland without woody components such as some of the Mitchell grass area. For such rangelands that are overgrazed, reduced grazing overall, and varying grazing intensity in relation to recent rainfall, may be successful at increasing ecosystem (and soil) C stocks as assumed by the Garnaut report. The second type is rangeland that is prone to woody thickening under grazing - generally semiarid tropical woodlands. For those, the use of grazing to foster woody thickening, followed by acceptance of reduced stocking rates in later years as the trees and shrubs come to dominate and exclude grass (and also acceptance not to re-clear), is an option to increase whole ecosystem C-stocks. The third type is those areas where grazing inhibits woody thickening, such as many temperate pastures of SE Australia which were established on cleared forested lands. For these, removal of grazing would allow the gradual recovery of forest and hence of high C stocks above and below ground. Where complete removal of grazing is envisaged for afforestation, consideration needs to be given for each area whether the most cost effective approach is to allow gradual recovery of native woody vegetation, or to plant or sow trees.

In any event, a cost of increased C-stocks for all three categories is long term reduction in production from domesticated animals sooner or later. A community gain, however, could potentially be increased biodiversity, though the reality of that would have to be confirmed. So the option of remunerating landholders for managing to increase biodiversity as well as increasing ecosystem carbon stocks needs consideration (Fensham and Guymer, 2009), but presents even more daunting quantitative baseline and verification issues than does C-stocks. In addition, the repercussions of increasing tree cover for regional water storages above and below ground needs consideration with regard to appropriate financial rewards and penalties.

5.2 Sequestration Opportunities

Given the subjectivity and multiple causes of pasture degradation with virtually no data available about what each means for soil C stocks, and also the tenuous relationship between the terms "degradation" and "overgrazing" (see above), any estimation the carbon sequestration potential of grazing management is necessarily highly approximate - perhaps even an exercise in wishful thinking.

5.2.1 Annual rates of sequestration

There is only one peer-reviewed measurement-based analysis (Conant and Paustian 2002) of grazing impacts on the potential annual rates of soil-C sequestration covering the whole of Australia. According to that global analysis, 11.2% of the Australia/Pacific region of the world was overgrazed (49 M ha out of 437 M ha), but 97.5% of that overgrazing was only "light", 2.3% being "moderate", and 0.2% "strong". Virtually none was classified as "extreme" for which recovery is deemed practically impossible. Regression analysis of the 22 global data points found in the literature (mostly in N. America) suggested that the annual increase in soil C, upon reducing grazing intensity, increased linearly with annual rainfall. It became increasingly positive for annual rainfall above 333mm and negative below 333mm annual rainfall. That is they extrapolated, counter-intuitively, that reducing grazing intensity in very dry areas (<333mm yr⁻¹) led to loss of soil C. There were, however, no data points at those low rainfalls.

For the Australia/Pacific region as a whole (which is essentially Australia in terms of land area), Conant and Paustian (2002) concluded that the average potential sequestration rate upon reduced grazing intensity, was 90 kg C ha⁻¹ yr⁻¹. Over the 49 M ha of land classified as overgrazed, this amounted to 4.4 Mt C yr⁻¹ of C sequestration potential (or 16 Mt CO₂-e yr⁻¹). Thus this published figure in the scientific literature is about 5% of the Garnaut estimate of 286 Mt CO₂-e yr⁻¹.

But there are problems with data available for the Conant and Paustian study:

- They found only 0.2% of the overgrazed land in Australia/Pacific region was “strongly” or “extremely” overgrazed, whereas the Tothill and Gillies study found much larger areas to be defined as “severely degraded” meaning that they were considered to be not economically recoverable. For Queensland they found that 17% of the pastures were severely degraded. Given the cyclic nature of degradation and recovery and the subjective assessments of degradation there is substantial room for divergent views of the degree of true degradation of any particular area.
- Conant and Paustian’s input data did not make reference to the woody thickening issue, which is so critical to many Australian rangelands.
- The Conant and Paustian study does not consider an interactive wildfire regime that plays a big role in the Australian pasture C-cycle.
- Eight out of the twenty two data points used in the Conant and Paustian study showed soil carbon loss rather than gain associated with reduced grazing intensity.
- The above-ground carbon stocks are not considered by Conant and Paustian.

Another approximation of the potential maximum soil C sequestration potential was made for Australian *tropical* rangelands by Ash *et al.* (1995). Based on extrapolation of measurements of the %C content of the top 100 mm of certain non-deteriorated, deteriorated and degraded land at northern Australian research sites, Ash *et al.* (1995) estimated that if the 43 M ha identified as deteriorated land recovered to non-deteriorated state then 315 Mt C would be sequestered. If this amount were sequestered over 40 years then the average rate would be 183 kg C ha⁻¹yr⁻¹ for the tropical rangelands.

Averaging the two very approximate estimates above (90 and 183 kg C ha⁻¹ yr⁻¹), we conclude tentatively for calculation purposes that deteriorated rangeland might be able to sequester approximately 140 kg C ha⁻¹ yr⁻¹ (513 kg CO₂ ha⁻¹yr⁻¹) over 40 years into the soil by reducing or eliminating grazing by domestic stock. However, to allow for the huge uncertainties involved we place a factor of 5 around that figure as an uncertainty range. What reduced stocking does to the above ground biomass C-stocks would depend on the complementary control burning that is performed. Without control burning to remove grassy fuel accumulation, the woody thickening may cease or decline under reduced grazing. However, over several decades the interactions of above ground biomass with wildfire and prolonged drought is complex and ill-understood.

Adopting a potential soil C accumulation rate of 140 kg C ha⁻¹yr⁻¹ under reduced grazing for the 67 Mha of deteriorated Queensland rangeland the annual rate of sequestration would be 34 Mt CO₂-e yr⁻¹. If that were able to be sustained over 40 years before saturation the cumulative increase in soil C stocks over 40 years, would be 1360 Mt CO₂-e. However, given that much of the deterioration is in the form of woody thickening, which might involve higher soil C stocks than non-deteriorated grazing, this figure must be viewed with caution. In the drier savannas, woody thickened land may suffer major tree death in prolonged droughts (Fensham, Fairfax and Ward, 2009). In such a regime, the cycles of woody growth and death in drought years may “pump” C into a standing stock of non-decomposing dead woody stems. Placing the nominal uncertainty factor of 5-fold around those values places the cumulative potential soil C-sequestration for Queensland in the approximate range 300-7,000Mt CO₂ over 40 years.

For the Queensland mulga country, Boyland (1973) indicated 32.6Mha in the Mulga and Channel Country bioregions. Of this we assume 51% is deteriorated (Tothill and Gillies (1992). With mulga lands being much drier than average Queensland rangelands, we adopt a C-sequestration potential of 70 kg C ha⁻¹yr⁻¹ (instead of the 140 kg C ha⁻¹yr⁻¹ for the rangelands as a whole) as a result of reduced grazing intensity. This yields a potential C sequestration over 40 yr of 170 Mt CO₂ falling within the uncertainty band of about 35 to 850 Mt CO₂

We do not have a continental figure for the deteriorated grazing land of Australia. There are some estimates that more than 50% may be degraded (e.g. Woods 1983; Mabbutt 1992; Dregne and Zhou 1992) but the value from Tothill and Gillies (1992) for all of northern Australian grazing lands was only 32% deteriorated (with another 12% degraded). Taking an intermediate value of 40% and applying this to 510 Mha (see Table 1.1), then 204 Mha may be considered deteriorated and amenable to improvement by management. This is three times the Queensland area of deteriorated land (67 Mha) so we simply note that the national figure could be three times the Queensland figure and double the uncertainty factor. Thus, the sequestration potential over 40 years adopted is 4000 Mt CO₂ with an uncertainty factor of 10x around that figure – namely in the range 400Mt to 40,000Mt CO₂

Adopting the same assumptions for all Australia’s mulga lands (150 M ha) as for those in Queensland, but with an uncertainty factor of 10x, the 40 yr sequestration potential is 780 Mt CO₂ falling in the uncertainty band of about 80 to 7800 Mt CO₂

5.2.2 Saturation of sequestration

For soils that are not so permanently waterlogged such that peat accumulates, soil organic matter does not accumulate indefinitely. For any given increase in the annual rate of input to the soil there is an upper limit to the amount of C-increase in the soil:

accumulation of soil C with continuing regular organic matter input reaches a steady state level at which rate of decay equals rate of input. For above-ground biomass too, an ecosystem that is not destroyed by an extreme event like fire reaches a point of maximum standing stock of C when annual death (and decay) rate equals annual new-growth. In addition there is a second type of soil C saturation at which the steady state saturation point is not increased by a further step up in the annual rate of input (Stewart *et al.* 2007). Thus an essential complement to estimating the initial rates of accumulation of above- and below-ground carbon following a grazing intensity reduction is how long accumulation will continue to the saturation point, and will a further decrease in grazing intensity further increase that steady state in C stocks? While the concept of saturation of the first type (steady state) is clearly correct, and that of the second type is probably correct for most situations, measurement-based quantification is unavailable for Australian rangelands.

5.3 Research needs and steps to implementation

Clearly there is a massive shortfall of data needed to back up and provide the information base on which to design a workable C-trading scheme involving alternative management strategies for the Australian rangelands. Thus, it is impossible to design a trading scheme involving increasing soil or ecosystem C stocks in the Australian rangelands within the next few years that will effectively and quantitatively ensure decreased net emission of greenhouse gases to the atmosphere. If the objective is considered worth pursuing relative to alternative surer approaches, then a massive research agenda over the next 2 or 3 decades is needed to establish the requisite information base. Some major research areas that need addressing include:

- A synthesis of all the accessible data available (published and unpublished) of soil C stocks in Australia grazing lands leading to an evaluation of gaps in order to develop a concerted measurement strategy to systematically complete a survey of the soil C stocks to at least 1m depth throughout the continent.
- Establishment of a continent-wide stratified network of permanent observation sites for routine monitoring at 5 to 10 year intervals of soil and above-ground carbon stocks down to at least 1m depth. For Queensland the stratification approach should take account of the 250 grazing land types that have recently been defined. This network should seek to integrate with the now-emerging national Terrestrial Ecological Research Network (TERN) to gain the benefits of linking the results to other ecological information such as biodiversity data. The purpose of the C-stock information gained is to equip the national long term system for “decarbonising” the economy with the basic knowledge of the existing terrestrial carbon stocks and their change with time as a result of non-managed change deriving from the impacts of atmospheric composition change and climate change, as well as managed emission reductions.
- Research trials set up in a spectrum of grazed vegetation types and regions to quantify the change in soil C stocks over at least a decade with change in grazing intensity, grazing management or destocking, and change in woody species density.
- Investigation of the possibility, and the C sequestration potential, of afforestation of those grade-D grazing lands that have been severely degraded by overgrazing.
- Research into the C-sequestration potential and other benefits of tree and shrub shelter belts within grazed landscapes.
- Investigation of the option of using frequent low intensity control burns of tropical grazing lands at the beginning of the dry season or end of the wet season to increase soil C stocks, including long-lived char, by eliminating the less frequent intense wild fires in the dry season that can cause decline in accumulated ecosystem C stocks.
- Work out a standardised but cost-effective methodology with sufficient accuracy and independent reproducibility for C-trading purposes to define the change in ecosystem C stocks as a result of specific management strategies.

5.4 Defining Uncertainty

The most critical factors behind the large uncertainty factors adopted in estimates of C-sequestration are:

- Vast lack of quantitative data on ecosystem carbon stocks and fluxes across Queensland (and Australia).
- Huge but largely undocumented natural spatial variability in ecosystem C stocks on all spatial scales (centimetres to kilometres) including the change with soil depth.
- Inability to formally quantify the uncertainties at this stage because of the large data shortage.
- Long time periods (e.g. >20years) for realistic hope of detecting whether a management plan did in fact change ecosystem (especially soil) C stocks.
- Lack of quantitative knowledge of the effects of management options on ecosystem C stocks.
- Incapability to determine accurately the baseline ecosystem carbon stocks if the requisite baseline is in the past.
- The unpredictability of the timing, magnitude and impact on ecosystem C stocks of natural disaster effects, notably wildfire, flood and insect herbivore plague.

- Lack of methodology to deal with lateral transfers of soil C across the landscape and into and out of Queensland and the continent as a result of soil erosion and wind erosion especially during major floods and dust storms.
- Uncertainty about the nature of the C-trading scheme details that will eventuate, the nature of which will affect the character of C-cycle quantification required.

5.5 Risk and Barriers to Implementation

For a sound scheme that leads to sustainable and permanent reduced emissions it is essential that risks and barriers are identified and taken properly into account of in the scheme's design. Some important barriers to designing and running a successful scheme are set out below.

5.5.1 Harmonising a short term market mechanism for CO₂ emission reduction with a long term ecological process of C sequestration having chaotic episodic elements

The lack of a scheme to use soil C sequestration as a GHG emission offset or tradable item is a barrier to implementation. Maintenance of high rangeland carbon stocks on the decadal to century timescale needed for climate change mitigation presents special challenges for its management via any short-term market-based incentive schemes operating on annual time-steps. There are several considerations. There are two steps to reducing CO₂ emission from the land, a) increasing the standing stock of carbon in the plants and soils, and b) holding those increased C stocks indefinitely, once they have reached their steady-state limit under the altered management regime, to keep the net accumulated C-stock from returning to the atmosphere. Most emphasis in discussion of C-trading is on remunerating a land holder for stage a). However, the issue of how the on-going management regime to sustain those higher C stocks, almost certainly involving reduced income from animal production, is achieved and rewarded indefinitely also needs to be addressed. If the continual remuneration ceases then the balance of factors for the landholder that lead to higher animal stocking rates and any associated lower C stocks may return. When the land is managed under leasehold to either a private owner or the State the remuneration regime will be more complex. When the lease or land is sold, the burden of the C-sequestration legacy may also have to be sold.

5.5.2 Establishing baseline stocks and flows for C-trading

In determining the remunerable change in CO₂ emissions associated with a planned change of management regime, there needs to be a baseline year for comparison of ecosystem (or soil) carbon stocks. One important determinant of the total ecosystem C and also the distribution-density of below ground carbon down the soil profile at any one time is the cumulative history of the population-density and types of the different plants. Thus application of simple formulae or deeming rules (in lieu of the preferable direct measurement) that do not take account of the history-dependent baseline will be flawed. Unfortunately the detailed vegetation history of particular sites is rarely documented, so direct measurement of the baseline C, in the baseline year, is generally essential for meaningful C-accounting. This of course is not possible if the mandated baseline year is in the past (e.g. 1990 for the Kyoto Protocol, or 2000 for Garnaut and the CPRS).

Not only should there be a baseline in the carbon stocks of the rangeland, but also a baseline net annual flux (source or sink) in the baseline year for that rangeland. Such a baseline flux will vary with current weather, rate of loss by erosion, current and recent past grazing management, and stage of the rangeland in the resource accumulation/resource conservation/disturbance/resource release adaptive cycle. The reaction of the ecosystem C-sink to a scheme of changed grazing pressure will vary according to where in that adaptive cycle the patch of vegetation was at scheme-start. A unit area for the scheme (such as a paddock, farm, or catchment) may be a composite of different land-patches at various stages in their adaptive cycles. The cost and complexity in determining this information for a scheme unit and in finding a way to factor that information into specifying how the agreed management regime has altered those stocks and fluxes on a year-by-year basis is a substantial cost-impediment to implementation.

A third baseline issue concerns documenting what the grazing intensity was before the start of the scheme and how it will change after the scheme starts. Prudent graziers already vary grazing pressure enormously over time according to the state of the weather and the state of finances. There is rarely a fixed stocking rate. During a prolonged drought a property may carry few stock for several years. After heavy rain, a property may be able to stock heavily for a couple of years based on the surge of growth. With no fixed grazing intensity or even systematic pattern of varying grazing intensity, it is challenging to define the baseline grazing regime and also the agreed new regime, which it is hoped will lead to net C-sequestration unless the new regime is complete destocking. Harper *et al.* (2007) using the Range-ASSESS model for West Australian rangelands concluded that 50% destocking would still lead to some ecosystem C loss in 80% of 5-year periods. Total destocking was necessary for consistent C-accumulation in the ecosystem.

5.5.3 Factoring out natural change in C stocks

Ecosystem C stocks naturally vary up and down through time irrespective of human management of the land. They vary on seasonal and annual time scales with climate variability, particularly in rainfall and temperature. They will also vary inter-decadally and on century timescales with global climatic change and the increasing atmospheric carbon dioxide concentration. These variations not only render the determination of both the baseline and managed changes in soil C stocks problematic, but also provide a difficult problem for factoring out global change influences that are not caused by the manager undertaking the C-trading. Using satellite imagery, Donohue *et al.* (2009) have estimated that between 1981 and 2006 the Australian vegetation cover has been increasing by an average of 0.07% yr⁻¹ representing an increase of 1.8% over 26 years. This overall greening trend of the continent, if it continues, would potentially be driving a C-stock change in the same direction that needs to be distinguished from any management driven change under a trading scheme.

5.5.4 Opportunity for fraud

Trading changes in ecosystem C stocks is replete with opportunity for fraudulent claims and financial transactions that are ineffective at securing permanently sequestered C. Being sure that the risk of fraud has been properly addressed is a major barrier to formulation of a successful C-sequestration scheme. The technical methodological potential for fraudulent activities and transactions relating to ecosystem carbon storage, leading to little or no actual positive climate benefits on the multi-decadal time-scale of climate change processes for GHG mitigation, is large. There are numerous routes for fraudulent claims of C sinks especially if the financial remuneration starts to flow before the sink in question has been positively quantified by onsite measurements. The potential timescale for such verifiability of soil C increases would typically be a minimum 10 to 20 years after the designated management change was implemented. If it is found that the cost of direct statistically significant validation by on-site measurement is so high, and so delayed, that indirect systems based on C-sequestration computer models and deemed default sinks or regionally averaged sinks needs to be adopted, then fraud will be especially problematic to counter. It will require that extremely well thought through and stringent regulatory measures be adopted, that a powerful compliance watchdog of both technical methodologies and financial dealings be instituted to ensure actual GHG emission reductions occur and persist over decades to centuries, that the correct people are rewarded for them, and that the wrong people are not rewarded.

5.5.5 Hydrological implications

The repercussions of increasing tree cover for regional water storages above and below ground needs consideration with regard to appropriate financial rewards and penalties for building up ecosystem C stocks. Hydrologically, there can be both benefits and costs. Trees tend to increase rainfall interception and retention but also, being deep rooted, to lower water tables and use more water than the grassy vegetation. Thus re-treesing to increase C-stocks above- and below-ground could reduce run-off into rivers and dams. However, the reduced runoff can be primarily from reduced storm-flow rather than base-flow (Wilcox *et al.* 2008), which is favourable for reducing surface soil C losses. The balance of hydrological pros and cons will therefore vary with rainfall regime, soil infiltration properties and geology and will differ for each region.

5.5.6 Transfer of C by erosion

Carbon can be lost or gained by erosion processes as well as lost by oxidation. Disappearance of topsoil from a paddock does not equate exactly to oxidation of its C to CO₂. One of the reasons that a paddock can lose C under grazing is that the reduced ground-cover exposes bare soil to wind and water erosion which removes some of the highest carbon topsoil. It is deposited somewhere else such as valleys and in sediments of dams or in estuaries, and via major dust storms well out to sea – even on New Zealand. The quantities of C involved in major events can be prodigious. Oxidation of such transported organic matter might be faster or slower than it would have been in its place of formation. But in any event any measured loss or gain of carbon by a paddock as a result of such lateral transport represents a challenging barrier to implementation of a carbon trading scheme on a farmer-by-farmer basis.

5.5.7 Kyoto Lands

Pasturelands were eligible for inclusion under Article 3.4 in national carbon accounting for compliance under the terms of emissions reductions targets of the Kyoto Protocol to which Australia is a ratified signatory. Unless there is an international agreement to revoke the terms of the Kyoto Protocol, any lands which were submitted to become "Kyoto lands" may have different rules applied by the Carbon Pollution Reduction Scheme to their emission reduction arrangements via subsequent C-trading than lands, which are not so constrained by this prior commitment.

5.5.8 Costs to the grazier

The costs of C sequestration to the property owner can be considerable and will need to be assessed by owners before entering into binding commitments. There is a conflict between maintaining production and sequestering C (Moore *et al.* 2001). Thus the grazier will receive less income from animal production. This reduced income stream will be forever or until the cost of paying society to release the CO₂ back to the atmosphere becomes less than the gain in re-intensifying the grazing.

Another cost is that of measuring the baseline C-stocks and testing the expected increase in C-stocks on an indefinite basis. While a modelling approach may be adopted initially to “deem” an annual ecosystem C accumulation rate for a particular agreed change in grazing management, it will be essential to test and reset the modelled rate of accumulation every decade or two for each patch of land. This will be necessary to ensure that C is actually being removed from the atmosphere and that correct financial compensation is changing hands in whichever direction it needs to go depending on whether C was actually accumulated or was lost from the land. The huge variability, on all space scales, of C-stocks per unit area, especially for the tussock and hummock grasses so common on the rangelands makes the detection of ecosystem C change (especially soil C change) against that statistical variability extremely expensive. Funding the eternal burden of checking that the sequestered C is still in place long after the C increase has saturated, will be a major impediment.

Another hidden cost, which might be regarded as an opportunity cost, is the value of the mineral nutrients that are inevitably sequestered with the C sequestered in organic matter (Passioura *et al.* 2008). Such minerals are garnered from the productive outputs of the land or must be applied as fertiliser or their availability will decrease. Each tonne of C in soil organic matter is associated with about 100-120 kg of N and 20 kg of P. These amounts, when bound in an enlarged pool of soil organic matter, are unavailable to plant production even though it is a pool that is “turning over”. The value of these elements if they were supplied at retail prices of fertiliser is around \$150-200 for the N and \$80- \$100 for the P at recent prices. Thus the opportunity cost of the minerals tied up would be around \$200-\$300 per t C sequestered. The current (February 2009) price of C on the Chicago Climate Exchange is about \$US7 to 8 per tC. These nutrients could be utilised for growth by grazing more heavily so that the soil organic matter status declines back down to the pre-sequestration level, and the nutrients released and the carbon converted to CO₂.

Bray and Golden (2009) modelled two grazing enterprises in Queensland and showed there was considerable scope to choose alternative management options to influence their GHG budgets. The alternative options had large impacts on both net C stores and carrying capacity of the properties, but the financial effects were not assessed.

5.6 Compliance and Auditing

The technology does not exist for adequate establishment of baseline terrestrial C-stocks for baseline dates in the past. The technology does exist for adequate measurement of future C-stocks for market based C-trading purposes (pending agreement to an accepted standardized methodology for C-trading purposes). However, the cost effectiveness of measurements for sufficient statistical certainty of putative C-sinks and sources as a result of agreed management changes is open to doubt and needs careful investigation before designing a scheme.

In any event, if ecological-C offsets and trading are to develop, they will emerge from an environment of very weak quantitative understanding into one of improving understanding. The improvements will be fast at first and continue for many decades. Accordingly the trading policies and terms enacted should be couched in forms that can be readily and routinely updated and upgraded to accommodate improvement in the science without disadvantaging early *bona fide* investors.

5.7 Other Benefits and Consequences

Collateral effects of sequestering more carbon into the grazed landscape are complex and include changes in biodiversity, hydrology, sediment movements and siltation of waterways, dams and reservoirs, nutrient budgets and potentially human infrastructure losses from wildfire.

5.8 Lateral Thinking

This chapter has concentrated on reduced grazing intensity but there are additional options to alter the carbon balance of rangelands.

There is the possibility, emerging from the literature reviewed, that for some sites soil carbon storage might increase with *increased* grazing intensity. This is scientifically perplexing and needs careful evaluation for possible opportunities in Australia.

On sites that are badly degraded (grade D in Queensland), a solution may be to permanently abandon grazing and instead plant trees and shrubs or halophytes, or encourage woody regrowth.

The planting of bands of trees in grazed rangelands (McKeon *et al.* 2009) may:

- Increase total landscape carbon stocks above- and below-ground.
- Not decrease landscape forage production as much as the fractional area of shelterbelt involved might imply.
- Increase water retention in the landscape and reduce water and wind erosion.
- Have favourable feedback effects on mesoclimate in the vicinity of the belts and also possibly on regional climate.
- Provide animal shelter in the cooler environment under the trees.
- If established as a wide-scale connected network, provide migration corridors facilitating wildlife adaptation to climate change.

Use regular controlled fire to increase landscape C-storage by increasing the use of low intensity grassland burns at the end of the wet season or early in the dry season to eliminate or reduce the frequency of intense burns that reduce ecosystem C stocks.

Each of these options need to be evaluated in terms of pros and cons, trade-offs and risks.

5.9 Contributors

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- Steven Bray Queensland Department of Employment, Economic Development and Innovation
- Christopher Dean Western Australia Forest Products Commission
- Damian Barrett Sustainable Minerals Institute, University of Queensland.

5.10 Research Groups, Research Activity and Focus

Australia

- Queensland Department of Environment and Resource Management;
- Queensland of Employment, Economic Development and Innovation, Queensland;
- Queensland Department of Environment and Resource Management Protection Agency;
- Forest Products Commission, WA;
- Department of Agriculture and Food, WA;
- Northern Territory Department of Regional Development, Primary Industry, Fisheries and Mines;
- Queensland University of Technology,
- Central Queensland University,
- CSIRO Sustainable Ecosystems

International

- Natural Resources Ecology Lab, Colorado State University, Fort Collins, Colorado USA

Research relevant to this topic includes:

- Land condition monitoring – Rapid “drive-by” assessment
- Land condition monitoring – D-condition mapping
- Land Condition monitoring – satellite imagery and ground cover indices
- Land Condition monitoring – ground sites
- Grazing land management
- Soil Carbon
- Grazing trials (both completed and currently active)
- Tree strips southern and central Queensland
- Infiltration assessment
- Infiltration and soil biological activity
- Soil emissions
- Economic analyses
- Impacts of fire
- Mulga regrowth monitoring

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Table 5-3: Methodology for estimating potential, attainable and base greenhouse gas sequestration/mitigation for rehabilitating overgrazed rangelands.

Option		Rehabilitate overgrazed rangelands, restoring soil and vegetation C-balance (includes mulga lands) Option does not include changes in direct livestock emissions from changes in stocking rate	Restoration of mulga country
Current or Business as Usual Net Carbon Storage (Mt CO ₂ -e) from 2010 to 2050		It is not known whether ecosystem C stocks or soil C stocks in Australian rangelands are increasing or decreasing. They may be decreasing in places where woody species are not thickening up and overstocking is occurring. But where grazing is leading to woody regrowth that is not cleared they will be mostly increasing.	
Net Potential* Carbon Storage (Mt CO ₂ -e) from 2010 to 2050	Australia	Adopting a figure for Australia as simply 3x the figure for Queensland and an uncertainty factor of 10, the national figure comes to 4000 Mt CO ₂ falling in the uncertainty range 300-40,000 Mt CO ₂ -e. 100 Mt/yr	Of the 150 M ha of Aust. mulga, we assume half are deteriorated and capable of sequestering 70 kg C ha ⁻¹ yr ⁻¹ under reduced grazing. This gives 780 Mt CO ₂ over 40 years falling in the uncertainty range of 80 to 7800 Mt CO ₂ . 20 Mt/yr
	Queensland	Of the 151 M ha of native pasture about 67 M ha is deteriorated. Assuming that deteriorated land can store 140 kg C ha ⁻¹ yr ⁻¹ in soil consistently over 40 years by reducing stocking rates, then the net potential is 1400 Mt CO ₂ -e from 2010 to 2040 with uncertainty of 5-fold (i.e. 300 to 7000 Mt CO ₂ -e) This soil gain may be offset by reduced tree thickening unless tree thickening is managed by strategic burning off of grassy fuel. 35 Mt/yr	Of the 32.6 M ha of Qld mulga, we assume half are deteriorated and capable of sequestering 70 kg C ha ⁻¹ yr ⁻¹ under reduced grazing. This gives 170 Mt CO ₂ over 40 years falling in the uncertainty range of 35 to 850 Mt CO ₂ . 4 Mt/yr
Functional Unit and Basic Algorithm Used to Calculate per Unit CO ₂ -e		Hectare Based on minimal literature assuming that 140 kg C ha ⁻¹ yr ⁻¹ is possible for soil sequestration	Hectare Based on minimal literature assuming that 70 kg C ha ⁻¹ yr ⁻¹ is possible for soil sequestration
Scaling Up Process		Multiplication by area	Multiplication by area
Attainable* Net Carbon Storage (Mt CO ₂ -e) and factors driving this translation	Queensland	Assuming that 50% of potential is attainable, then 700 Mt CO ₂ -e is attainable with 5-fold uncertainty (i.e. 140-3500 Mt CO ₂ -e) 18 Mt/yr	Assuming that 50% of potential is attainable, then 85 Mt CO ₂ is attainable with 5-fold uncertainty (i.e. 17-425 Mt CO ₂) 2 Mt/yr
Base* Net Carbon Storage (Mt CO ₂ -e) and factors driving this translation	Queensland	Assuming that 25% of the potential is likely, then 350 Mt CO ₂ -e is attainable with a 5-fold uncertainty (i.e. 70 to 1750 Mt CO ₂ -e over 40 years) 9 Mt/yr	Assuming that 25% of the potential is likely, then 40 Mt CO ₂ is attainable with a 5-fold uncertainty (i.e. 8 to 200 Mt CO ₂ over 40 years) 1 Mt/yr

* See Chapter 1 Section 1.2 Methodology for explanation of potential, attainable and base.

6 Mitigation of emissions from savanna burning

Alan Andersen and Scott Heckbert

6.1 Definition and Scope

Tropical savannas cover the northern third of Australia, and represent 80% (160 million ha) of Queensland. They are the continent's most fire-prone biome, with savanna burning contributing 3% of Australia's total accountable (non-CO₂) greenhouse gas (GHG) emissions (about 1% for Queensland). Fire also has a strong but very uncertain influence on (Kyoto non-compliant) carbon sequestration. A large proportion of burning is the result of uncontrolled, relatively high intensity wildfires occurring late in the dry season. There is very significant potential for using strategic prescribed burning early in the dry season to reduce the intensity and extent of savanna burning in a GHG abatement context.

6.2 Analysis Section

Tropical savannas are the dominant ecosystems of northern Australia, and contain about 30% of Australia's terrestrial carbon stocks. They are also the continent's most fire-prone biome, with up to half or more of many landscapes being burnt each year. There is growing national and international interest in reducing the extent and severity of these fires in a GHG abatement context (Williams *et al.* 2005; Heckbert *et al.* 2008). This has the potential to transform regional economies in northern Australia, especially by providing livelihood opportunities for remote Aboriginal communities where mainstream economies are very limited (Whitehead *et al.* 2008).

Savanna fires influence GHGs atmospheric levels through the release of both methane and nitrous oxide. This combination is a significant contribution to the nation's accountable (non-CO₂) GHG emissions. Our scientific understanding of these emissions is well-developed, as are the tools and technologies for their measurement (Russell-Smith *et al.* 2009). The feasibility of reducing such emissions has been demonstrated by the Western Arnhem Land Fire Abatement (WALFA) project; where strategic prescribed burning early in the dry season has substantially reduced the extent of late-season wildfires and therefore overall area burnt. CSIRO has calculated that about 5 Mt/yr of CO₂ equivalents could potentially be abated nationally (0.77Mt/yr in Queensland) through this process (Heckbert unpublished data; see Heckbert *et al.* 2008 for analytical methodology).

Savanna burning potentially has a greater effect on GHG emissions through its impact on carbon sequestration, by influencing tree growth and mortality, the incorporation of organic carbon in the soil, and the production and storage of char. These effects are not Kyoto compliant, and our scientific understanding of these dynamics is not so well developed. There has been a significant body of work on the effects of fire on savanna tree productivity and carbon sequestration, mostly conducted in the Top End of the NT (Chen *et al.* 2003; Williams *et al.* 2004; Cook *et al.* 2005; Beringer *et al.* 2007). These studies suggest that Australian savannas are net carbon sinks, sequestering up to 3 t C/ha/yr, and this could be substantially increased with reduced fire severity (Williams *et al.* 2004). However, all these studies have been conducted in sub coastal areas subject to cyclones, where the vegetation is likely to be still re-growing from past cyclone damage. It is therefore not possible to generalise their results to more inland regions, where cyclone impact is lower, and lower rainfall results in lower productivity. A study of changes in tree cover in Queensland savannas indicated that they were also significant carbon sinks (Burrows *et al.* 2002), but these ecosystems are likely to be recovering from past mortality from drought (Fensham *et al.* 2005, 2009).

There is particular uncertainty around the effects of fire on below-ground C sequestration in Australian savannas, where as much as 75% of savanna carbon resides, up to 150 t C ha⁻¹ (Chen *et al.* 2003). Soil carbon concentrations in Australia's savannas are lower than in coastal forests, but their contribution to continental soil C stores are far greater due to their extensive area (Webb 2002) and substantial stores of stable, black soil carbon (Lehmann *et al.* 2008). A reduction in the frequency of burning and intensity of fires (by shifting from late-season to early season burns) may result in greater sequestration of carbon into the soil. For example, hot fires, occurring late in the dry season when fuel loads are high, may cause a substantial loss of carbon from the soil due to removal of above and belowground litter inputs and consumption of organic matter in top soil layers if soil temperatures are above 50°C (Knickers 2007). On the other hand, fire suppression could also result in a loss of soil carbon over time due to a decrease in black carbon inputs (such as char) and grass litter or fine root inputs. However, this is purely speculation, as we know very little about char production by savanna fires.

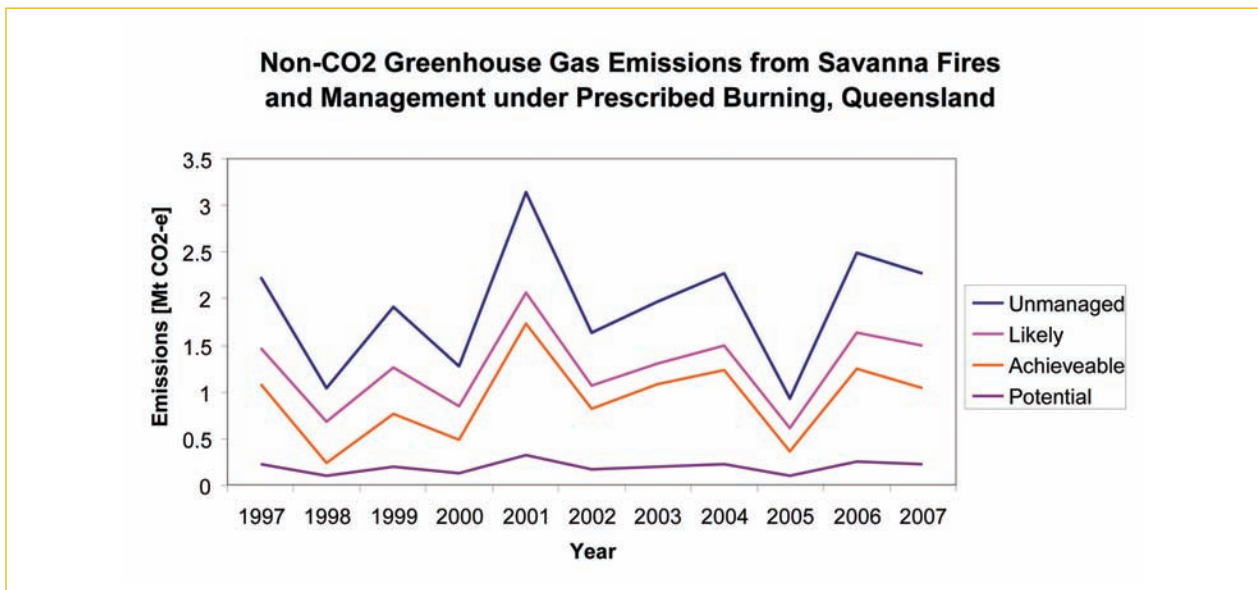


Figure 6-1: Fire emissions from retrospective application of the “potential”, “achievable” and “base” scenarios compared to business as usual with little or no prescribed burning (unmanaged).

Due to all these uncertainties, in this chapter we have not attempted to model potential effects of different fire management options on C-sequestration by savanna ecosystems. However, we note that such an analysis of C-sequestration is required for full GHG accounting in relation to savanna burning.

6.3 Defining Uncertainty

There is uncertainty in three areas:

Scientific: There is still work to be done on characterising seasonal variation in emission factors for methane and nitrous oxide, but most uncertainty relates to the effects of fire on C sequestration as outlined above. Estimates of ecosystem sequestration are required from representative sites across the savanna zone. There is a particular need for the establishment of long-term monitoring sites subject to different burning regimes, with special attention paid to below-ground processes. There is also a need for a greater understanding of the effects of different burning regimes on biodiversity, such that carbon and biodiversity values can be appropriately balanced. CSIRO is conducting such fire experiments at two sites in the Darwin region, but such studies are required elsewhere across northern Australia. Lastly, unlike non-CO₂ emission abatement, C sequestration in above and belowground pools will saturate over time following implementation of appropriate fire management. Therefore, there is uncertainty about the time-frame over which C sequestration benefits from savanna burning can be claimed, and how to maintain fire management in areas where C levels have saturated and no further sequestration opportunities exist.

Feasibility: The feasibility of reducing the extent of savanna burning through targeted prescribed burning is likely to vary markedly between regions, depending on both biophysical (remoteness, terrain, vegetation type) and socioeconomic (human capacity, funding) factors. The WALFA project is achieving its target of a 34% reduction, but is particularly well-resourced (both financial and human), and feasible levels of abatement in other regions are unclear.

Carbon policies and rules: There is very considerable uncertainty here, both for accountable emissions (the acceptance of WALFA-type activities as formal offset projects) and more particularly for (Kyoto non-compliant) sequestration.

6.4 Risk and Barriers to Implementation

The major barrier to implementation of savanna burning for abatement of methane and nitrous oxide emissions is policy uncertainty around its recognition as legitimate offset activity. For carbon sequestration, the major barriers are the connected issues of lack of technical understanding/validation protocols, and its Kyoto non-compliance. There is significant risk that abatement activities based solely on non-CO₂ emission abatement may not reflect whole-of-system GHG dynamics. For example, although unlikely, (currently accountable) emission-friendly fire suppression activities could ultimately lead to greater GHG emissions in the long-term from reductions in stable (char) pools and a greater probability of destructive wildfires due to high fuel loads. The issue of carbon property rights is also a potential challenge to the implementation of savanna burning for GHG abatement.

6.5 Compliance and Auditing

As outlined previously, there are well-developed compliance and auditing protocols for Kyoto-compliant non-CO₂ emissions (Russell-Smith *et al.* 2009), but such protocols are poorly developed for C sequestration. There has been important recent progress with the development of consistent accounting protocols and measurement technologies needed for establishing feasible monitoring and auditing systems for soil carbon sequestration. For example, mid-infrared (MIR) spectroscopy is a technique currently being developed and calibrated nationally for Australia's key soil types that provides a method for calculating soil carbon stocks and pools (charcoal and labile) that is both robust and inexpensive (Janik *et al.* 2007). Soil carbon data from MIR soil analyses and elsewhere is being used to calibrate and refine the predictive capabilities of the RothC soil carbon model within the National Carbon accounting System (NCAS) framework. These measurement and modelling technologies, along with standardised sampling methodologies, can be implemented to improve our understanding of soil carbon storage under different savanna burning regimes.

6.6 Other Benefits and Consequences

An important feature of savanna burning for GHG abatement is that it has valuable co-benefits. First, there is significant concern in many savanna regions that fire frequency is so high that it is threatening significant conservation values (Andersen *et al.* 2005). In regions of extremely high fire frequency, such as Cape York Peninsula, the Top End and the northern Kimberley, fire abatement would have significant biodiversity benefits. This is a feature of the WALFA project, where the high incidence of wildfire sweeping through the region in recent decades has significantly degraded the conservation values of adjacent Kakadu National Park. A second highly significant co-benefit is the provision of livelihood opportunities in remote areas of Australia, especially for Indigenous communities. In addition to paid jobs, it provides an opportunity for Aboriginal people from remote communities to re-establish traditional land management activities and to conserve their traditional ecological knowledge. Finally, gains from reduced savanna burning could be used by pastoralists as offsets against emissions from livestock.

6.7 Lateral Thinking

The above analysis has not considered belowground emissions of nitrous oxide and methane following fire (see Dalal and Allen 2008), which requires further investigation.

6.8 Contributors

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6.9 Research Groups

CSIRO

- Sustainable Ecosystems (Cross-CSIRO research led by Alan Andersen: fire and savanna dynamics, carbon economics, Indigenous livelihoods; across northern Australia, but with a particular focus on the NT)
- Marine and Atmospheric Research (Led by Mick Meyer: fire emissions, throughout northern Australia)

State

- Bushfires NT (Led by Jeremy Russell-Smith: Fire mapping and auditing, throughout northern Australia)
- QLD Department of Environment and Resource Management (Led by Ram Dalal: soil carbon impacts of grazing and burning in Qld and NT)

Universities

- Charles Darwin and Melbourne Universities (Led by Lindsay Hutley, Stefan Maier (CDU), Stephen Arndt and Steve Livesley (UoM): savanna GHG emissions, NT)

6.10 References

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Table 6-1: Methodology for estimating potential, attainable and base greenhouse gas sequestration/mitigation for savanna burning.

Option	Mitigation of emissions from savanna burning														
Current or Business as Usual Fire Emissions (Mt CO₂-e) from 2010 to 2050	Annual emissions of non-CO ₂ GHG from fire on savannas (see spatial extent in report) for business as usual, based on 1995-2007 data														
	<table border="1"> <thead> <tr> <th>AUS</th> <th>QLD</th> </tr> </thead> <tbody> <tr> <td>14Mt/yr</td> <td>2.3Mt/yr</td> </tr> <tr> <td>560Mt over 40 years</td> <td>92Mt over 40 years</td> </tr> </tbody> </table>	AUS	QLD	14Mt/yr	2.3Mt/yr	560Mt over 40 years	92Mt over 40 years								
	AUS	QLD													
	14Mt/yr	2.3Mt/yr													
560Mt over 40 years	92Mt over 40 years														
Net Potential* Emissions Removal (Mt CO₂-e) from 2010 to 2050	Annual emissions of non-CO ₂ GHG from fire on savannas (see spatial extent in report) for 90% reduction														
	<table border="1"> <thead> <tr> <th>AUS</th> <th>QLD</th> </tr> </thead> <tbody> <tr> <td><i>Total Emissions</i></td> <td></td> </tr> <tr> <td>1.4Mt/yr</td> <td>0.23Mt/yr</td> </tr> <tr> <td>56Mt over 40 years</td> <td>9.2Mt over 40 years</td> </tr> <tr> <td><i>Abatement/Offset</i></td> <td></td> </tr> <tr> <td>12.6Mt/yr</td> <td>2.1Mt/yr</td> </tr> <tr> <td>504Mt over 40 years</td> <td>84Mt over 40 years</td> </tr> </tbody> </table>	AUS	QLD	<i>Total Emissions</i>		1.4Mt/yr	0.23Mt/yr	56Mt over 40 years	9.2Mt over 40 years	<i>Abatement/Offset</i>		12.6Mt/yr	2.1Mt/yr	504Mt over 40 years	84Mt over 40 years
	AUS	QLD													
	<i>Total Emissions</i>														
	1.4Mt/yr	0.23Mt/yr													
	56Mt over 40 years	9.2Mt over 40 years													
	<i>Abatement/Offset</i>														
12.6Mt/yr	2.1Mt/yr														
504Mt over 40 years	84Mt over 40 years														
Functional Unit and Basic Algorithm Used to Calculate per Unit CO₂-e	Spatial model (Heckbert <i>et al.</i> 2008) uses: emissions equations as outlined in NGGI Fire frequency data as per ACRIS Management assumptions														
Scaling Up Process	Spatial scale accounted for; data organised at various scales, current refinement activities.														
Attainable* Net Emissions Removal (Mt CO₂-e) and factors driving this translation	Annual emissions of non-CO ₂ GHG under managed fire regime, which assumes a 34% (Meyer) reduction														
	<table border="1"> <thead> <tr> <th>AUS</th> <th>QLD</th> </tr> </thead> <tbody> <tr> <td><i>Total Emissions</i></td> <td></td> </tr> <tr> <td>7.8Mt/yr</td> <td>1.0Mt/yr</td> </tr> <tr> <td>312Mt over 40 years</td> <td>40Mt over 40 years</td> </tr> <tr> <td><i>Abatement/Offset</i></td> <td></td> </tr> <tr> <td>6.2Mt/yr</td> <td>1.3Mt/yr</td> </tr> <tr> <td>248Mt over 40 years</td> <td>52 Mt over 40 years</td> </tr> </tbody> </table>	AUS	QLD	<i>Total Emissions</i>		7.8Mt/yr	1.0Mt/yr	312Mt over 40 years	40Mt over 40 years	<i>Abatement/Offset</i>		6.2Mt/yr	1.3Mt/yr	248Mt over 40 years	52 Mt over 40 years
	AUS	QLD													
	<i>Total Emissions</i>														
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	<i>Abatement/Offset</i>														
6.2Mt/yr	1.3Mt/yr														
248Mt over 40 years	52 Mt over 40 years														
Base* Net Emissions Removal (Mt CO₂-e) and factors driving this translation	Annual emissions of non-CO ₂ GHG under managed fire regime, which assumes a cost benefit is passed (@\$20t/CO ₂ -e)														
	<table border="1"> <thead> <tr> <th>AUS</th> <th>QLD</th> </tr> </thead> <tbody> <tr> <td><i>Total Emissions</i></td> <td></td> </tr> <tr> <td>9.2Mt/yr</td> <td>1.5 Mt/yr</td> </tr> <tr> <td>368Mt over 40 years</td> <td>600Mt over 40 years</td> </tr> <tr> <td><i>Abatement/Offset</i></td> <td></td> </tr> <tr> <td>4.8Mt/yr</td> <td>0.77Mt/yr</td> </tr> <tr> <td>192Mt over 40 years</td> <td>31 Mt over 40 years</td> </tr> </tbody> </table>	AUS	QLD	<i>Total Emissions</i>		9.2Mt/yr	1.5 Mt/yr	368Mt over 40 years	600Mt over 40 years	<i>Abatement/Offset</i>		4.8Mt/yr	0.77Mt/yr	192Mt over 40 years	31 Mt over 40 years
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	<i>Abatement/Offset</i>														
4.8Mt/yr	0.77Mt/yr														
192Mt over 40 years	31 Mt over 40 years														

* See Chapter 1 Section 1.2 Methodology for explanation of potential, attainable and base.

7 Carbon storage in post-1990 plantations

Stephen Roxburgh

7.1 Definition and Scope

For the Australian national GHG accounts, post-1990 (or 'Kyoto') forests are defined as land areas of a minimum size of 0.2ha, supporting woody vegetation with a canopy cover of 20% or more, and with a height of 2m or more. For a parcel of land to be eligible for inclusion under the accounting rules it must have been non-forested on the 31 December 1989, must currently support forest (according to the definition above), and this forest must have arisen due to the 'direct human-induced conversion...through planting, seeding and/or the human-induced promotion of natural seed sources'. In the Australian accounts this represents softwood and hardwood plantations (DCC, 2008a).

The post-1990 forests covered in this report include only those plantations that were established specifically for hardwood and softwood timber production. Plantations specifically for carbon sequestration (i.e. not harvested) are covered under the 'Carbon Forestry (plantations)' options. The sequestration quantum is the fixation of atmospheric CO₂ through plant growth.

7.2 Analysis

The aim of this chapter is to provide estimates for the future sequestration capacity (2010-2050) of existing post-1990 forests, and the potential sequestration capacity due to the establishment of new plantations. A thorough analysis of the net sequestration of these forests would therefore require:

1. Projecting changes in the carbon stocks of existing post-1990 plantations from now to 2050, inclusive of growth sequestration, harvesting and replanting, and storage in harvested products.
2. Making some projections of where new plantations are expected to be developed, their size, and the time course of establishment, together with their expected management/harvesting regimes. Based on this, estimates of new plantation growth and sequestration, including the fate of harvested products, would be made up until 2050.
3. Making decisions on whether to include the potential impacts of climate change, and associated impacts such as altered water availability and changed disturbance regimes on plantation growth.

Such a comprehensive undertaking was beyond the scope of this report. However to provide some estimates (both nationally and for Queensland) we have adopted a simpler approach that combines historical sequestration estimates from the NCAS with existing analyses on projected changes in the area of new plantation establishment 2010-2050, and expert knowledge.

Note that comprehensive accounting should also include the sequestration/release of the harvested product, and any GHG emission due to harvesting, transport and processing. Consistent with national reporting rules, these are not included in the estimates below. In addition, GHG emissions associated with decomposition and burning should also be included, although, in a sustainably managed plantation estate, annual CO₂ emissions (including harvested products, and losses through decomposition and fire) are equal to annual CO₂ uptake by trees; only non GHG emissions (which are not taken up by the forest) need be included (e.g. May *et al.* In press).

7.2.1 Historical and projected changes in plantation area

Historical changes (1990-2007) in the national plantation area (Figure 7-1) and for the state of Queensland (Figure 7-3) were obtained from national plantation inventory statistics (Gavran and Parsons 2008). Projected (future) changes in plantation area were obtained from two sources. First, 'high', 'medium' and 'low' projections for 2030 at the national scale (Figure 7-1), and for Queensland in the years 2012, 2015 and 2030 (Figure 7-3), were provided by Mark Parsons and colleagues at the Bureau of Rural Sciences. These projections are based on current plantation areas, recent rates of expansion, and estimates of areas of new plantations planned by major operators in the plantation forest industry. The projections assume many companies have reached or are reaching their targets in several regions, and estate areas are stabilising as harvesting of maturing stands increases. The 'high' level assumes that all currently planned managed investment scheme targets will be achieved and that industrial plantation programs will be continued at current planned levels until 2030. The 'medium' and 'low' projections assume that proportions of those targets will be achieved. Taken together, these projections represent a range of possible 'business as usual' scenarios.

The second source of plantation area projections are taken from the report by Lawson *et al.* (2008; Tables 3, 5, 7), who used a modelling approach to explore the potential of forestry (including commercial plantation forestry) for carbon sequestration under a range of carbon price scenarios. The three scenarios are the 'business as usual' or reference case, and two scenarios exploring the possible impact of the introduction of carbon trading based on the Carbon Pollution Reduction Scheme (CPRS), with hypothetical carbon price points of \$20.88/t CO₂ (the CPRS-5 scenario) and \$29.10/t CO₂ (the CPRS-15 scenario). Full details of the analyses and the underlying assumptions can be found in Lawson *et al.* (2008).

At the national scale the 'business as usual' rate of plantation expansion is expected to decline over the coming decades, and to approach a steady state of approximately 2.4 Mha by 2050 (Figure 7-1). The introduction of a CPRS-5 carbon price is predicted to lead to a continuation of the recent historical linear increase in plantation area, and to reach a total area of approximately 4.9 Mha by 2050 (Figure 7-1). Increasing the price of carbon further (CPRS-15) is predicted to lead to an acceleration of plantation establishment, culminating in approximately 6.3 Mha by 2050 (Figure 7-1).

The plantation areas for Queensland under the 'business as usual' case are predicted to continue to increase and to reach a total area of approximately 0.37 Mha by 2050 (Figure 7-3). Under the CPRS-5 scenario the increase in plantation area is predicted to be greater than under the CPRS-15 scenario (Figure 7-3), contrary to the national trend (c.f. Figure 7-1). This is because at the higher carbon price the viability of environmental plantings increases, leading to a predicted switch away from commercial plantation forestry to plantings solely for carbon sequestration. The Queensland trend is opposite to the national pattern because of the greater relative potential for environmental plantings in that state.

Also plotted on Figure 7-1 is the national 'Plantations 2020' target of 3 Mha. When it was introduced the Plantations 2020 vision sought to increase the current plantation area (about 1 Mha at the time) to 3 Mha by 2020, and in so doing enhance regional wealth creation and international competitiveness in the industry (Thompson 2008). Current 'business as usual' projections are predicted to fall below this target, at around 2.3-2.4 Mha by 2020.

7.2.2 Historical and projected changes in plantation sequestration

Historical changes (1990-2006) in national plantation sequestration (Figure 7-2) and sequestration for the state of Queensland (Figure 7-4) were obtained from the National Greenhouse Gas Inventory (DCC 2008a,b). The units are tCO₂-e/yr and represent the net amount of carbon sequestered over each year. Future sequestration rates were based on two sources. For the national estate, the fate of existing (1990-2006) plantations was estimated using the 'Estate' mode of the National Carbon Accounting Toolbox (NCAT) (R. Waterworth pers. comm.). Projections to 2050 indicate a levelling off of plantation carbon stock by around 2030, and hence a gradual decline in annual sequestration to zero at that time (i.e. when the amount of carbon in the national plantation estate has levelled off, the net change in carbon from one year to the next, i.e. the sequestration, is zero). Predictions of the sequestration of additional new plantation areas post-2006 were taken from Lawson *et al.* (2008; tables 4, 6 and 8), for the three scenarios described above (reference or 'business as usual', CPRS-5, and CPRS-15). Because the Lawson *et al.* (2008) sequestration estimates pertain only to new plantings post-2006, total plantation sequestration was estimated by adding the NCAT projections (of the future sequestration of existing plantings) to the Lawson *et al.* (2008) projections (of the future sequestration of new plantations).

At the national scale, and under the 'business as usual' scenario, annual sequestration is predicted to decline until approximately 2030 and then stabilise at an annual rate of approximately 4 Mt CO₂-e/yr. The introduction of a carbon price is predicted to increase plantation establishment, and hence sequestration, up to approximately 34 Mt CO₂-e/yr by 2050 under CPRS-5, and 50 Mt CO₂-e/yr under CPRS-15. Average sequestration over the period 2010-2050 is predicted to be 9.2, 24.1 and 32.2 Mt CO₂-e/yr for the business as usual, CPRS-5 and CPRS-15 scenarios respectively.

For Queensland and under business as usual, sequestration rates are predicted to increase from approximately 0.3 Mt CO₂-e/yr to approximately 1.5 Mt CO₂-e/yr by 2050; under CPRS-5 and CPRS-15 the predictions at 2050 are approximately 4.5 and 2.9 Mt CO₂-e/yr respectively. Average sequestration over the period 2010-2050 is predicted to be 1.0, 2.6 and 1.8 Mt CO₂-e/yr for the business as usual, CPRS-5 and CPRS-15 scenarios respectively. The lower predicted sequestration under the higher CPRS-15 carbon price again reflects the predicted switch from commercial plantation forestry to environmental carbon plantings at the higher carbon price.

7.3 Defining Uncertainty

Overall, the National Carbon Accounting System (NCAS) 1990-2006 estimates of sequestration for plantation forests have a low level of uncertainty as estimates are based on high-resolution national-level satellite image analysis of plantation area, combined with well calibrated models of plantation species growth (FullCAM). The major uncertainty relates to the prediction of future sequestration. The 'high' 'medium' and 'low' projections of plantation area in Figure 7-1 and Figure 7-3 are based on a number of assumptions, for example that current business circumstances that affect the amount of investment funds available are assumed to

continue; a large majority of the funds available for the past several years have been raised by managed investment schemes. These schemes are currently being severely affected by difficulties in raising capital for land acquisition and the market for the schemes may contract for some years due to the general turmoil in financial markets. These factors add to the uncertainty of achieving the "high" level of expansion. These projections also assume that Government programs that are financing plantation expansion in some States will continue at the planned rates until they reach their targets; all of these are planned to terminate by 2012.

Predictions of sequestration in response to the introduction of a carbon trading scheme are even more uncertain. A full discussion of the assumptions underlying the CPRS-5 and CPRS-15 predictions shown in Figure 7-2 and Figure 7-4 are given in Lawson *et al.* (2008).

7.4 Risk and Barriers to Implementation

The major barriers to implementation are most likely to be economic, such as transport costs, the increasing price and availability of good production land (in Queensland), the non-performance of existing plantations potentially limiting reinvestment, the availability of processing plants, and in some cases the requirement for building new processing plants in developing plantation areas. Some of the economic constraints are already factored into the high, medium and low projections, as described above. Other limiting factors include competition with existing land uses (particularly agriculture), the social acceptance of an expanding plantation forest industry, and the development and testing of suitable genetic stock for establishing commercial plantations in new areas.

As highlighted by Lawson *et al.*'s (2008) results, a potential opportunity (and also source of uncertainty) is the introduction of a national carbon trading scheme. For Queensland's timber plantation forests an initial carbon price of around \$20/tCO₂ is projected to result in an economically viable potential area of 0.447 Mha over the period 2007-2050, 0.307 Mha above the reference case; however increasing the initial carbon price to \$29/t CO₂ leads to projected area of just 0.293 Mha. This is due, as discussed above, to the relative increase in the viability of carbon-only plantings as the price of carbon increases.

7.5 Compliance and Auditing

Post-1990 forest sequestration is currently included as part of National GHG reporting activities using the NCAS.

7.6 Other Benefits and Consequences

Expansion of the plantation forestry estate clearly has a number of consequences over-and-above carbon sequestration. Plantation forests can provide biodiversity habitat and can help ameliorate salinity. There are also the economic and social benefits of a viable and expanding plantation industry. On the negative side growing forests can reduce water yield as a result of increased transpiration, and can hence have detrimental impacts on catchment hydrology. There are a number of active research projects investigating the potential impacts of plantation expansion on hydrology.

7.7 Contributors

- Mark Parsons Bureau of Rural Sciences, Canberra
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- Rod Fensham Queensland Herbarium, Toowong
- Philip Polglase CSIRO Sustainable Ecosystems, Canberra
- Barrie May CSIRO Sustainable Ecosystems, Mt. Gambier

7.8 Research Groups

- National Forest Inventory, Bureau of Rural Sciences.
- NCAS team, Department of Climate Change.
- CSIRO Sustainable Ecosystem, Forest Biosciences

7.9 Research Activity and Focus

Two agencies provide state and national scale analysis of plantation growth and establishment. They are the National Carbon Accounting System (NCAS) group at the Department of Climate Change, and the National Forest Inventory (NFI) group at the Bureau of Rural Sciences, within the Department of Agriculture, Fisheries and Forestry.

The NCAS publishes, on an annual basis, national and state-level greenhouse gas inventories in accord with international reporting requirements for land-based emissions and sinks. The latest inventory is for 2006 (DCC 2008a, b) and provides emissions profiles for all sectors, including land-use, land-use change, and forestry, which under Kyoto accounting rules includes new forestry plantings since 1990, and deliberate human-induced forest removal.

The NFI produces 5-yearly reports on the state of Australia's forest resources (e.g. BRS 2008), as well as annual 'National Plantation Inventories' that report statistics such as the areas of new plantations established on a state-by-state basis, the breakdown of softwood vs. hardwood plantations, and plantations by tenure (e.g. Gavran and Parsons 2008). Much of this information, for both native and plantation forestry, is regularly integrated into a single compendium of data tables and other information in the *'Australian forest and wood production statistics'* (e.g. ABARE 2008).

7.10 References

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Table 7 1: Methodology for estimating potential, attainable and base greenhouse gas sequestration/mitigation for carbon storage in post-1990 plantations.

<p>Option</p>	<p>Carbon storage in post-1990 plantations (primary goal is commercial biomass harvest)</p> <p>Note:</p> <p>The 2020 vision sought to expand the plantation forest area nationally from approximately 1 million ha in 1996 to 3 million ha in 2020. Project targets collated by the National Plantation Inventory indicate that the total area could reach just 2.3–2.4 million hectares by that time (Parsons <i>et al.</i> 2007).</p>
<p>Current or Business as Usual Net Carbon Storage (Mt CO₂-e) from 2010 to 2050</p>	<p>Current annual sequestration is around 23 Mt/yr nationally (= 1.9 million ha), and 0.28 Mt/yr for Queensland (= 0.25 million ha). This represents approximately 4% and 0.2% of annual national and state GHG emissions respectively.</p> <p>Business as usual projections for Qld indicate an increase in annual net sequestration rate from around 0.35 Mt CO₂-e/yr in 2010 to around 1.5 Mt CO₂-e/yr by 2050, with an average sequestration over the period 2010-2050 of around 1 Mt CO₂-e/yr.</p> <p>National projections indicate a decline in sequestration from around 23 Mt CO₂-e/yr currently, to around 4 Mt CO₂-e/yr in 2030, corresponding to a stabilisation of the national plantation estate. Average sequestration over the period 2010-2050 is predicted to be around 9 Mt CO₂-e/yr</p>
<p>Net Potential* Carbon Storage (Mt CO₂-e) from 2010 to 2050</p>	<p>Estimates of potential sequestration by the hardwood plantation subset of carbon forestry (Section 9; Table 9-4) are also relevant for industrial plantings.</p> <p>Australia</p> <p>The national estimate for potential storage given in Table 9-4 is 30,000 Mt CO₂-e, however this value combines areas suitable for both hardwood plantings and environmental plantings. Given the high level of uncertainty surrounding these estimates, the total carbon forestry figure, net of environmental plantings, can be used as a guide (16,000 Mt CO₂-e or 400 Mt CO₂-e/yr).</p> <p>Queensland</p> <p>Using the same assumptions on area allocated to environmental plantings, remaining carbon storage by hardwood plantation would be in the order of 3,880 Mt CO₂-e over the period 2010-2050 for Queensland (97 Mt CO₂-e/yr). For comparison, the equivalent business as usual projections for industrial plantations are 40 Mt CO₂-e.</p> <p>For comparison, the equivalent business as usual projection for industrial plantations nationally is 360 Mt CO₂-e over 40 years.</p> <p>The estimates of biophysical potential applied to commercial plantation establishment therefore greatly exceed the current plantation estate, and are orders of magnitude greater than what is realistic due to limitations of market demand, existing and future processing capacity (including the requirement to build new processing facilities and infrastructure), and associated transport costs (Polglase <i>et al.</i> 2008).</p>
<p>Functional Unit & Basic Algorithm Used to Calculate per Unit CO₂-e</p>	<p>Functional unit is state-level or national-level emissions estimates. CO₂-e emissions are extrapolated from historical NCAS inventory data 1990-2006 (DCC, 2008) using existing BRS plantation expansion predictions, modelling of plantation expansion and associated sequestration (Lawson <i>et al.</i> 2008), and expert knowledge.</p>
<p>Scaling Up Process</p>	<p>NCAS forest sequestration estimates (historical) are calculated using a fine-scale spatial (sub-hectare) analysis of land cover using remote-sensing, combined with a full system carbon accounting model (FullCAM).</p>
<p>Attainable* Net Carbon Storage (Mt CO₂-e) and factors driving this translation</p>	<p>Queensland</p> <p>Depending on the carbon price scenario (business as usual, CPRS-5 or CPRS-15), the attainable mean sequestration over the period 2010-2050 was predicted to be approximately 9-32 Mt CO₂-e/yr nationally, and approximately 1-3 Mt CO₂-e/yr for Queensland.</p> <p>Ave 2 Mt/yr</p>

Base* Net Carbon Storage (Mt CO₂-e) and factors driving this translation

Queensland

Figures 7-2 and 7-4 demonstrate that the base net carbon storage from commercial post-1990 plantation forests will depend strongly on the introduction and subsequent effectiveness of a national-scale carbon trading scheme, and the initial price of carbon.

Base sequestration will also be impacted by such factors as the current global financial situation.

In the absence of a carbon trading scheme base sequestration might resemble the 'low' estimate shown in Figures 7-2 and 7-4, with corresponding mean sequestration rates over the period 2010-2050 of around 0.5-1.0 Mt CO₂-e/yr for Queensland, and perhaps 5-9 Mt CO₂-e/yr nationally. This corresponds to net storage over the period 2010-2050 for Queensland of 20-40 Mt CO₂-e, and 200-360 Mt CO₂-e nationally.

The establishment of a carbon trading scheme, with an initial carbon price in the range \$20 - \$30/t CO₂, might see these rates increase by a factor of 2-3, but given current market (and policy) uncertainty, projections are very difficult to make.

* See Chapter 1 Section 1.2 Methodology for explanation of potential, attainable and base.

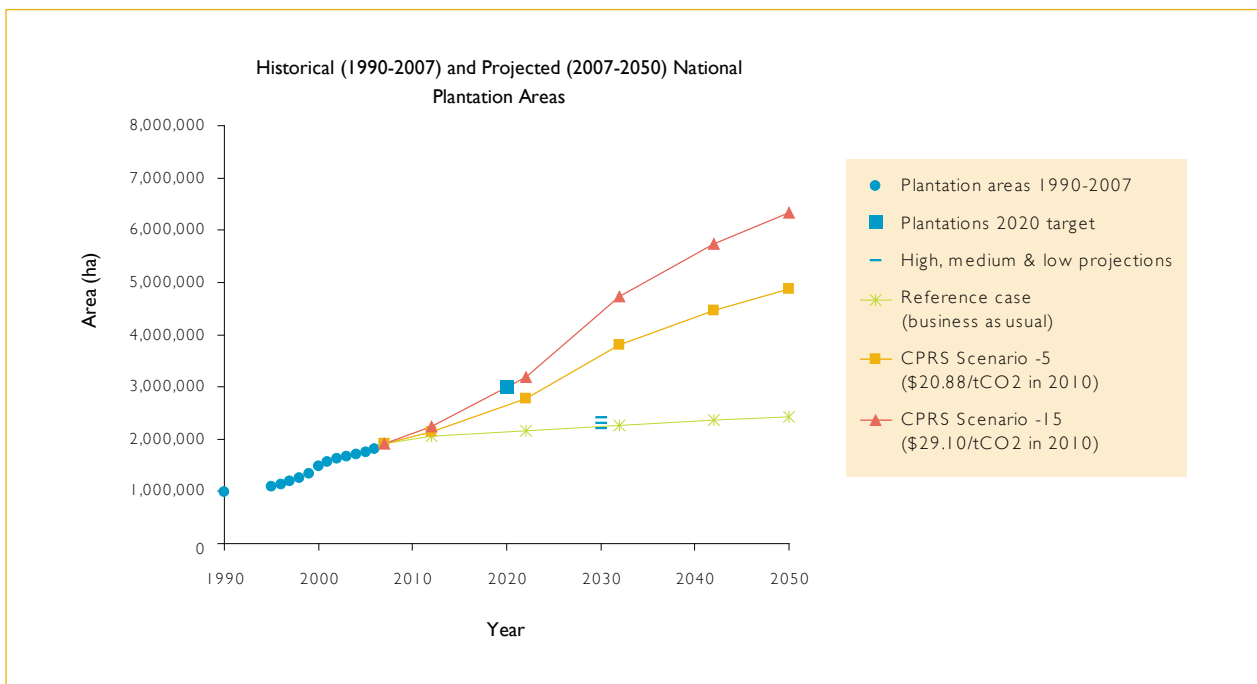


Figure 7-1: Historical and projected national plantation areas. Historical plantation areas are from Australian National Plantation Inventory statistics (Garvan and Parsons 2008). The high, medium and low projections at year 2030 are from M Parsons (pers. Comm.) as described in the text. The reference case (business as usual) and CPRS scenarios are from Lawson et al. (2008). The two CPRS scenarios correspond to modelled projections of changes in plantation area under two initial (2010) carbon prices of \$20.88/tCO₂ (CPRS-5) and \$29.10/tCO₂ (CPRS-15).

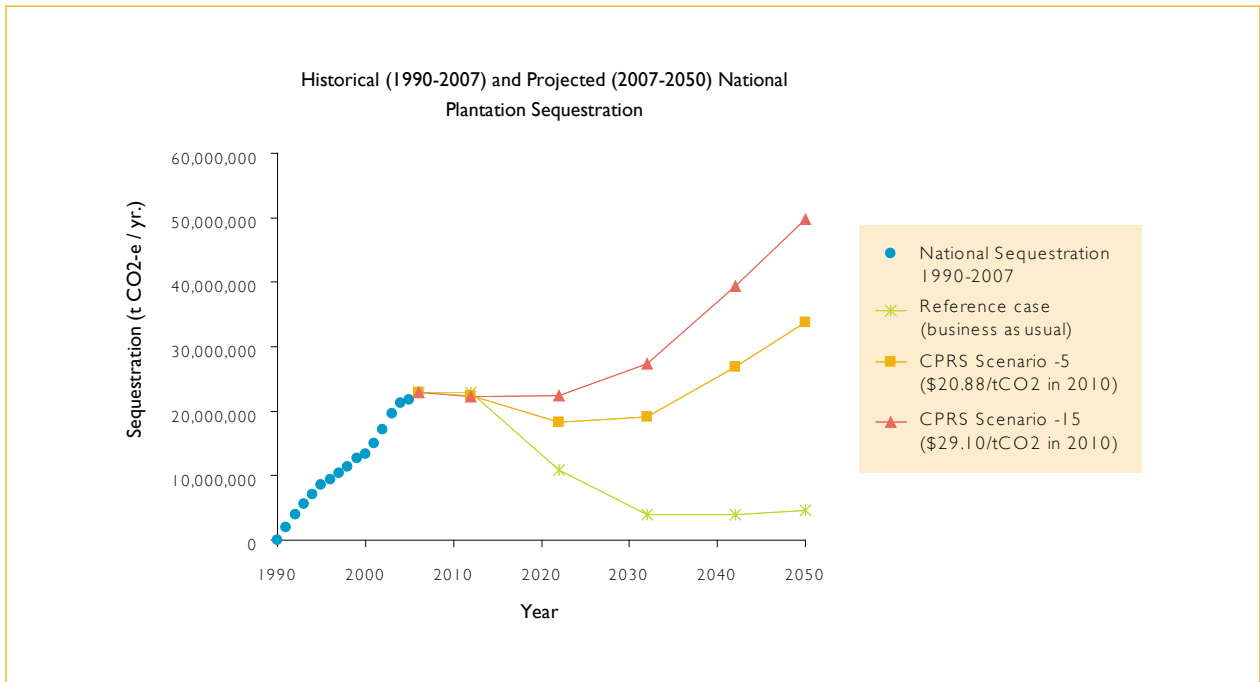


Figure 7-2: Historical and projected national plantation sequestration. Historical sequestration is from the National Greenhouse Gas Inventory (DCC, 2008a). The reference case (business as usual) and CPRS-5 and -15 scenarios combine sequestration projections of the fate of existing plantations from a National Carbon Accounting Toolbox analysis (R. Waterworth, pers. comm.) and projected sequestration from new plantings (tables 4, 6 and 8 of Lawson et al. 2008). See text for further details.

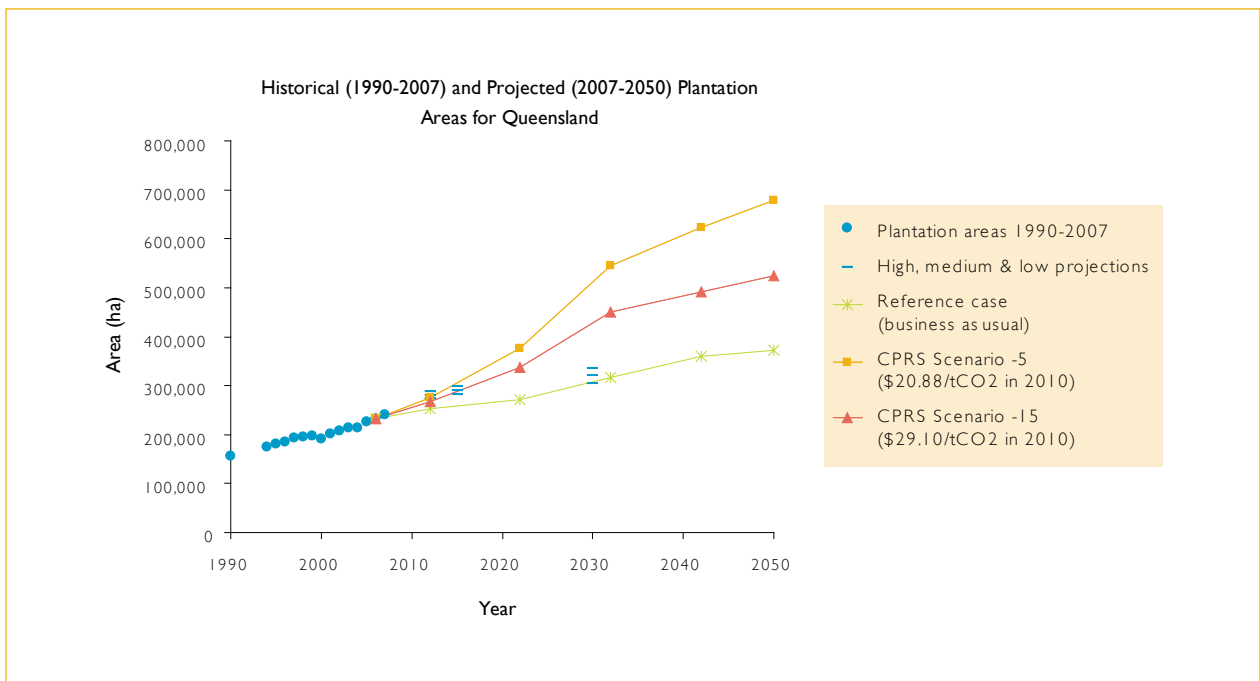


Figure 7-3: Historical and projected plantation areas for Queensland. Historical plantation areas are from Australian National Plantation Inventory statistics (Gavran and Parsons 2008), as described in the text. The reference case (business as usual) and CPRS scenarios are from Lawson et al. (2008). The two CPRS scenarios correspond to modelled projections of changes in plantation area under two initial (2010) carbon prices of \$20.88/tCO₂ (CPRS-5) and \$29.10/tCO₂ (CPRS-15).

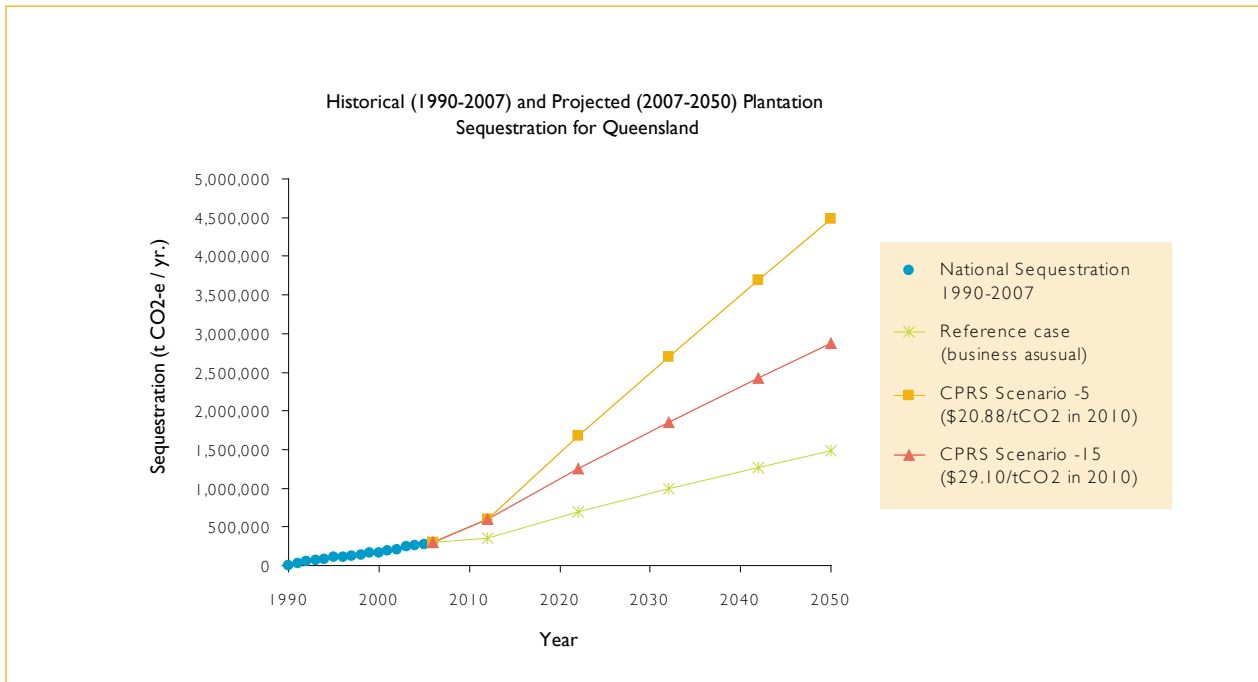


Figure 7-4: Historical and projected plantation sequestration for Queensland. Historical sequestration is from the National Greenhouse Gas Inventory (DCC, 2008b). The reference case (business as usual) and CPRS-5 and -15 scenarios combine sequestration projections of the fate of existing plantations based on trends from a National Carbon Accounting Toolbox analysis (R. Waterworth, pers. comm.) and projected sequestration from new plantings (tables 4, 6 and 8 of Lawson et al. 2008). See text for further details.

8 Increase carbon stocks in pre-1990 eucalypt forests

Stephen Roxburgh

8.1 Definition and Scope

In a recent study focussing on carbon stocks in south-eastern Australian native eucalypt forests, Mackey *et al.* (2008) sought to draw attention to: (i) the large carbon stocks that currently reside in forests that have not been subject to timber harvesting or other anthropogenic disturbances; (ii) the potential for re-sequestration of carbon previously lost from these forests due to harvesting or other anthropogenic disturbances, and; (iii) to emphasise that protection of (i) and recovery of (ii) can play a role in broader climate change mitigation activities. Their report also gave an indicative estimate of the carbon sequestration potential of these forests given land use history. This chapter provides further analysis on this latter question nationally and for the state of Queensland.

8.1.1 Carbon Carrying Capacity

The key feature of the Mackey *et al.* (2008) analysis, and primary aim of their report, was the spatial prediction of forest Carbon Carrying Capacity (CCC). This carrying capacity represents the potential biomass and soil carbon that a forested landscape can store accounting for the impacts of natural disturbances such as fire, but excluding the impacts of harvesting. Their analysis used a combination of field survey, modelling and GIS to derive a spatial prediction of CCC across the eucalypt forests of SE Australia. Because this CCC baseline is derived from existing field survey data collected from unlogged forests, it encapsulates past natural disturbance regimes and environmental conditions. If (as is almost certain) climatic conditions and disturbance regimes change in the future, then the CCC estimate can be used as a basis for quantifying how forest carbon storage might change under these future conditions.

8.1.2 Carbon Sequestration Potential

The impact of harvesting reduces carbon stocks below CCC. In contemporary forests that have/are undergoing harvesting, the difference between the current standing biomass and soil carbon (= Current Carbon Stock; CCS) and CCC therefore represents the direct anthropogenic 'harvested' impact, and is called the Carbon Sequestration Potential (CSP). Using these concepts Mackey *et al.* (2008) proposed that the protection of forests from future harvesting (albeit still subject to natural disturbance) will allow them to recover back towards their CCC, and that the magnitude of this recovery could contribute to a broader strategy of native forest management for GHG mitigation.

Although not the primary focus of their report, Mackey *et al.* (2008) also provided an initial indicative estimate of what the CSP of their study region might be as a means of relating the magnitude of terrestrial carbon stock changes to emissions and the radiative forcing effect. This estimate is very approximate because of uncertainties such as deficiencies in our current state of knowledge of current carbon stocks, little data on the losses of carbon due to harvesting, possible changes in CCC over time resulting from changing climate and atmospheric CO₂ concentration, and due to the large spatial and temporal scales involved. Therefore, the estimate of CSP should not be interpreted as a specific target for use within a formal mitigation scheme. Rather, this initial calculation represents a first attempt at quantifying the magnitude of these numbers for Australian native forests. Continuing work at ANU, particularly on quantifying current forest carbon stocks, will refine these initial estimates further, and will undoubtedly lead to further refining and development of the concepts as well.

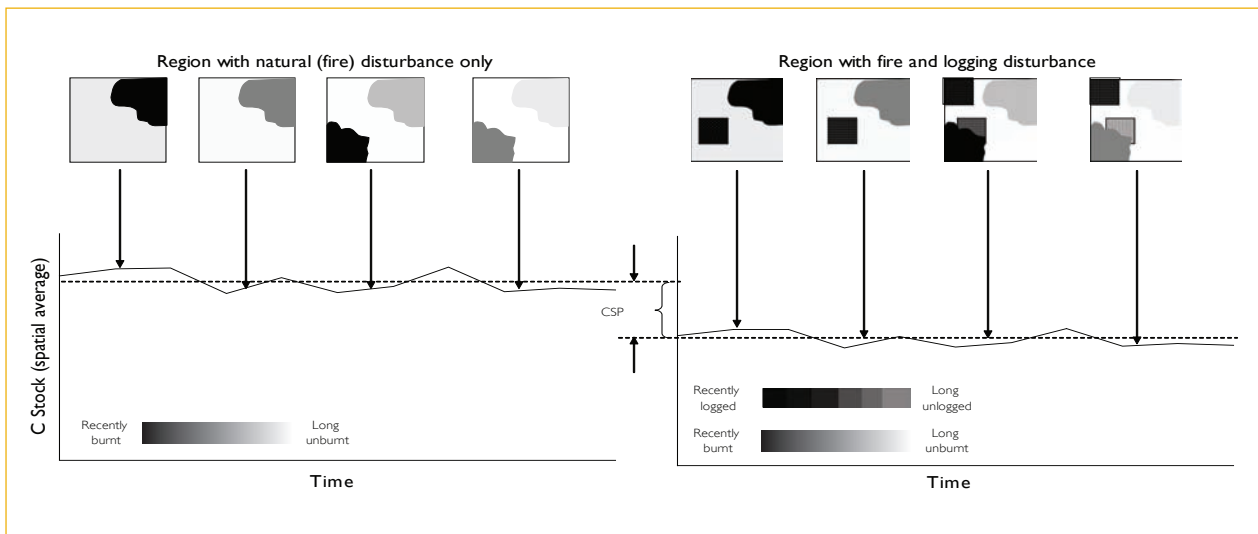


Figure 8-1: Illustration of the above concepts. A hypothetical example with two forested regions both subject to natural disturbance, but with the region on the right also undergoing timber harvesting. The boxes represent the regions, and show the spatial and temporal variation in disturbance and harvesting. The dotted lines represent the average over space and time of the forest carbon stocks in each region. The difference between these lines is the Carbon Sequestration Potential (CSP).

The scope of the analysis by Mackey *et al.* (2008) included eucalypt forests greater than 10m tall and with a canopy cover greater than 30%, corresponding to the National Vegetation Information System (NVIS 3.0) Major Vegetation Groups 2 and 3 (DEWR 2005). The spatial extent was 14.5 million ha, which included the eucalypt forests of Tasmania, Victoria and New South Wales, and a partial coverage of southern Queensland. The calculations involve the sequestration of CO₂ through forest growth. In Mackey *et al.* (2008) the sequestration potential was expressed after transformation by an equivalence factor to relate the carbon stored in the forest to the radiative forcing effect of that mass of carbon emitted as CO₂ to the atmosphere (see Costa and Wilson (2000), cited in Mackey *et al.* (2008), for a discussion of the equivalence calculation). However to allow the sequestration by the different options considered in this report to be compared, it is the actual quantity of GHG stored that is required (in units CO₂-e); hence in this report no adjustments are made to account for the radiative forcing effect.

8.2 Analysis Section

To provide estimates of carbon sequestration potential both nationally and for the state of Queensland, the original estimate of Mackey *et al.* (2008) was refined slightly.

The overall approach was to use the simple dynamic carbon model described in Roxburgh *et al.* (2006), calibrated using the CCC estimates summarised in Table 1 of Mackey *et al.* (2008). A description of the analysis methodology can be found in Appendix S1 of Roxburgh *et al.* (2006). This modelling approach provides a dynamic framework for investigating the potential impacts of historical logging on the stocks and flows of carbon through the forest estate, and also the potential rates of sequestration following release from logging. Consistent with the definition of CCC and Figure 8-1, natural disturbances such as fire are not explicitly modelled; rather, their impacts are assumed to be embedded within the field survey data used in the derivation of CCC (Mackey *et al.*, 2008). The overall approach is based on a number of simplifying assumptions, and as noted below the uncertainty is very high.

The key components of the re-analysis are as follows.

For their initial analysis Mackey *et al.* (2008) assumed total ecosystem carbon stocks (living + litter + soil) in areas subject to harvesting to be currently 40% below CCC, based on Roxburgh *et al.* (2006).

The assumption of 40% soil carbon loss following logging is uncertain, as Roxburgh *et al.* (2006) did not include soil carbon in their analysis, and empirical data on the proportion of carbon loss from soil due to harvesting is available from only a few studies. Rab (1994) found that, following logging in Mountain Ash forests of the Victorian Central Highlands, on average the soil organic carbon content in the top 10 cm decreased by 38% in the general logging area and by greater amounts on primary snag tracks and log landings. These losses were measured 13 months after logging and were attributed to the impacts on soil physical properties. Using a chronosequence of harvesting of managed north eastern red spruce in eastern North America, Diochon *et al.* (2009) determined that soil carbon stores decreased, to a depth of 50cm, to 50% of the level measured for intact forest in a 30 year period following

logging. It took approximately 100 years post-harvest for soil carbon stores to return to the intact forest level. In that study the reduction in soil carbon was attributed to increased rates of microbial respiration associated with the disturbance of the soil profile and exposure to oxygen of previously deeply buried organic matter. However, it is likely that (i) less intrusive harvesting methods, such as selective logging, would result in lower soil carbon losses, and (ii) soil carbon at depths greater than 10cm or 50cm is likely to be relatively more protected.

To allow for the possibility of lower soil carbon loss, two analyses are presented below. In the first a loss of 40% for both biomass and soil carbon in response to logging activity is assumed. This provides both national and Queensland-based estimates consistent with the original analysis of Mackey *et al.* (2008). In the second, soil carbon loss was not prescribed; rather, following logging, the subsequent flow-on effects to the soil carbon pool were determined by the internal dynamics of the model, i.e. reduced soil carbon inputs due to reduced above-ground biomass and litter. Importantly, this assumes no direct impact of logging activity on soil carbon due to changes in surface microclimate, enhanced soil respiration and soil erosion; only indirect effects resulting from reduced biological inputs.

A second source of uncertainty is the temporal pattern and extent of historical harvesting. The Kioloa region where the Roxburgh *et al.* (2006) study was based, and on which the above 40% reduction is based, may have been historically logged more intensely than some other forests (Raison and Squire 2007), and therefore the results may not be representative of the broader forest estate. Another method for estimating reduction in biomass due to harvesting is the use of log removal statistics from native forests, to provide an alternative estimate of logging impact (ABARE 2007).

To achieve a 40% decline in above-ground biomass (over a 160 year harvesting period; with an approximate start of timber harvesting around 1850), requires within the model a constant annual logging removal equivalent to 1.3% per year of the total estate (by mass). As an alternative, log removal statistics (ABARE 2007), combined with a number of assumptions, were used to convert reported harvested log volumes to carbon mass. The ABARE logging statistics used were for the period 1996 – 2007, not an average over the 160 years. Rates of logging were lower during this recent period due to both a smaller area harvested and lower harvesting intensities than previously. Additionally, there are areas that have been harvested more than once without growing back to CCC. The assumptions used in the conversion include an expansion factor to account for losses associated with tree harvesting and processing (Ximines *et al.* 2005). In the calculations below this factor was assumed to be 2, i.e. 1 t of harvested product requires a forest removal of 2 t biomass. The other major assumptions to convert harvested volume to mass are a carbon content of 50%, and wood basic density of 0.5 t dry matter/m³. This provided an alternative lower estimate of 0.4% per year (current log removals from Queensland native forests are around 0.2 Mt C/yr., and 5 Mt C/yr nationally (ABARE, 2007)). Applying the revised value of 0.4% yielded a predicted decline in above-ground biomass of 17% below carrying capacity. The implications of assuming a constant annual 'average' removal rate as opposed to varying the rate with time are discussed under 'Defining uncertainty' below.

The areal coverage of eucalypt forest was taken from RAC (1992), and is summarised in Table 8-1. RAC (1992) also provides estimates for the proportion of those forest types that were unlogged (as at 1992), and these are also given below. This allows estimates of the total estate CSP to be made. Because the table includes the complete state of Queensland, and also Western Australia, the total area (16.5 million ha) is somewhat more than the study area on which the Mackey *et al.* analysis was based (14.5 million ha).

Table 8-1: Native tall forest areas, and % logged (RAC 1992). Areas (ha x 1000).

Forest type	Queensland	Total continent
SE wet eucalypt forest		4063
SE Ash forest		1483
SE Coastal eucalypt forest		3775
Central coast eucalypt forest	1741	4240
NE coastal eucalypt forest	2734	2738
SW wet eucalypt		184
Total	4475	16483
% forest area logged	82.5	49.2

The calculations for both Queensland and nationally are therefore based on two scenarios; one assuming an average annual harvest rate of 1.3%/yr and a 40% decline in both biomass and soil carbon, i.e. consistent with Mackey *et al.*'s (2008) original analysis; and one assuming 0.4%/yr; with biomass and soil carbon losses predicted dynamically from the model. These two scenarios were designed to encompass a range of the uncertainties in the underlying data, including differences in forest harvesting methodologies, uncertainties over the historical spatial and temporal patterns of forest removal, and uncertainties over the response and regrowth characteristics

of native forests following logging. The analysis could be improved through defining regional differences in the above attributes, for example including state-level differences in harvesting practices (e.g. group selection vs. selective removal, and whether the coupes were burnt prior to re-establishment), and stratifying the calculations accordingly.

Figure 8-2 shows an example output of the model. The model is initiated at CCC steady state using estimates given in Mackey *et al.* (2008). In the run shown, harvesting continues until 2010, followed by recovery (sequestration). The two lines for each carbon pool represent the different harvest rate assumptions.

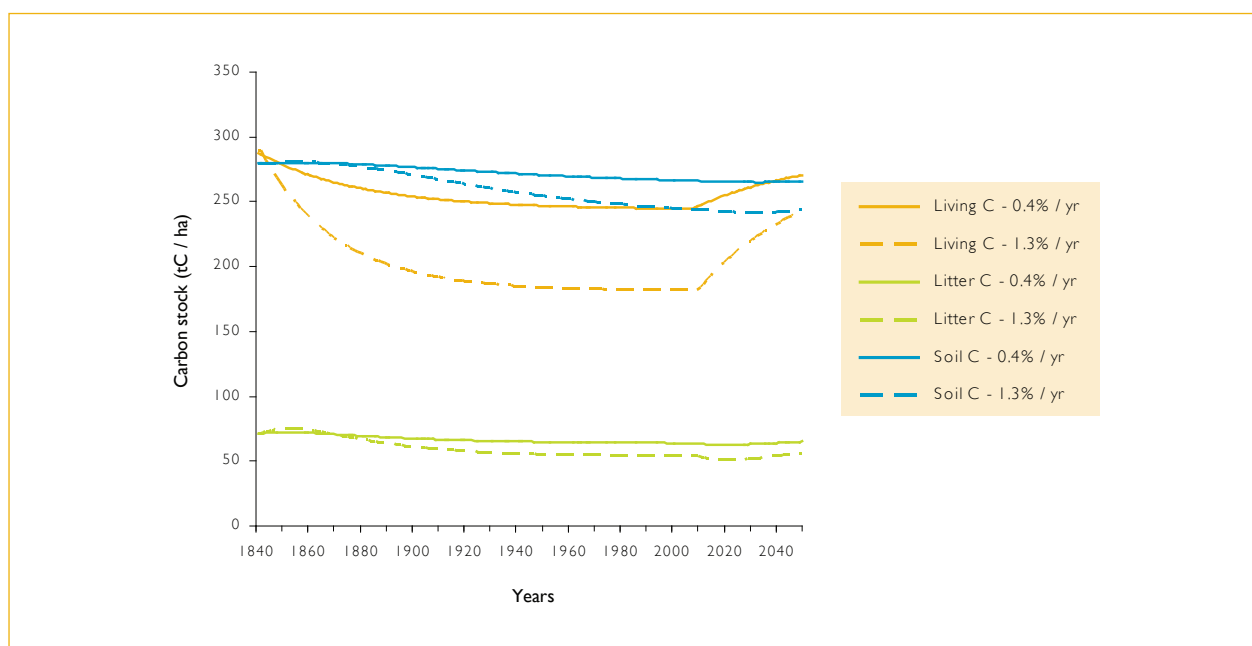


Figure 8-2: Example of model output for the national estate with carbon stocks expressed on a per-hectare basis – see Table 1 of Mackey *et al.* (2008).

The full results, on a decade-by-decade basis are given in the data section. In summary, at the national scale and assuming all logging ceased in 2010, average sequestration rates over the period 2010-2050 were in the order 19-74 Mt CO₂-e per year. For the state of Queensland the rates were in the order 8-34 Mt CO₂-e/yr. These correspond to approximately 3-13% and 5-20% of Australia's and Queensland's total GHG emissions respectively. If cessation of logging was delayed until 2025, then the sequestration rates become approximately 12-52 Mt CO₂-e per year for the national analysis, and 6-24 Mt CO₂-e per year for Queensland. This corresponds to approximately 2-9% and 3-14% of Australia's and Queensland's total GHG emissions respectively.

The 1.3%/yr harvesting scenario described above provided national and Queensland-based estimates broadly comparable to the methodology employed by Mackey *et al.* (2008). However there are important differences.

(i) The predicted sequestration potential of 7.5 Gt CO₂-e by Mackey *et al.* (2008) was an estimate for the total recovery potential, i.e. over the long-term. In contrast, the analysis in Table 8-1 predicted just the recovery over the first 40 years following the cessation of logging, which was predicted to be approximately 3 Gt CO₂-e (=40 years x 74.2 Mt CO₂-e/year). The pattern and quanta of sequestration beyond 2050 was not investigated, but given the calibration of the model of this scenario to the data in Mackey *et al.* (2008), the long-term sequestration prediction from the model is expected to be consistent with that reported in Mackey *et al.* (2008).

(ii) Mackey *et al.* (2008) presented their results in two forms. The first was the actual quanta of carbon sequestered, consistent with the analyses above. The second (as described under '1.1.2 Carbon Sequestration Potential') was an estimate based on an equivalence calculation to reflect the radiative forcing effect of the equivalent mass of carbon in the atmosphere. In that calculation the predicted 7.5 Gt CO₂-e sequestration potential translates to the equivalent of avoiding emissions of 136 Mt CO₂-e per year over the next 100 years (Mackey *et al.* 2008). To avoid confusion, readers need to be aware that these are different methods for expressing sequestration quanta, and that only the former is used in this report.

(iii) The land area under production forest tenure differs, with the current study using the RAC (1992) figures and the Mackey *et al.* (2008) study using the CAPAD (2004) figures. The larger area of production forest in 1992 combined with the logging removal and CCC figures gives a lower proportion of carbon reduction per hectare due to logging.

(iv) The Mackey *et al.* (2008) report focussed on forests in south east Australia. This chapter uses the average CCC from south east Australia to derive estimates of CSP nationally and for Queensland. However, forests on these other regions may well have lower average CCC.

8.3 Defining Uncertainty

There are very large uncertainties surrounding the estimates. These arise from a number of sources.

To calculate the CCC of the current forest estate requires sampling a large number of unlogged forest remnants. A key assumption is that the sites on which CCC are based are:

- a representative sample of spatial variability in forest growth in relation to environmental variables across the entire unlogged forest estate.
- a representative sample of spatio-temporal natural disturbance regimes (particularly fire). It is assumed the data used to calculate CCC include samples of unlogged but naturally disturbed vegetation, across a representative range of successional stages of recovery, potential including both very recently disturbed, as well as long-undisturbed.

This assumption is important but difficult to test, as it requires knowledge of the actual spatio-temporal variation in natural disturbance history of the forest estate, the spatio-temporal variation in other attributes relating to site quality, and the site histories from where the data were collected.

The estimates of current carbon stocks from the model are based on predictions using assumed constant historical long-term rates of logging intensity (1.3% and 0.4%/yr). This is unsatisfactory because historical records show timber removals varied significantly over time, and have been declining over recent decades (Raison *et al.* 2007). The implication for the modelling is that the predicted emissions profile is sensitive to the historical time course of the logging disturbance, and therefore assuming a constant rate should be regarded as, at best, a first approximation. The analysis could therefore be refined through imposing a time-course of timber removal, rather than the assumed constant.

There are large uncertainties surrounding the estimate of the current carbon stock of the forest estate, and the subsequent prediction of carbon sequestration potential. This will be greatly improved by the current work at ANU that is combining the spatially-explicit GIS layer of predicted CCC (Mackey *et al.* 2008) with estimates of historical harvesting and using remote sensing. Spatially-explicit field based estimates of actual current carbon will also be useful.

Projecting into the future is difficult. The calculation of the carbon carrying capacity (CCC) baseline requires carbon stock data collected from a large number of unlogged but otherwise disturbed sites. This baseline data therefore embeds within it past disturbance history and other sources of natural variability. As noted above, if conditions change in the future, e.g. if the fire regime changes or there is significant climate change, then this calculated historical baseline needs to be adjusted and estimates of sequestration potential based on that baseline would need to be recalculated.

8.4 Risk and Barriers to Implementation

There are a number of risks and barriers to implementation:

Figure 8-1 shows that the spatial and temporal scales involved in the calculations need to be large enough to encompass variation in forest site quality and patchiness in disturbance history. Therefore the spatial scale of application must also be large. For example the concept cannot be applied at a single site, or even at a landscape. This is because a particular site might have a reduced carbon stock (and hence a potential for sequestration) because it is recovering from a recent disturbance such as wildfire or windthrow. In this case most of the difference between CCS and CCC will be due to natural disturbance, and not logging, and hence would not be claimable. It is therefore important to draw a distinction between the minimum and maximum carbon stocks attainable at a particular location, and the minimum and maximum attainable carbon stock when averaged over the larger areas and longer timeframes at which CCC is calculated. In the former the range could span low carbon stocks (such as will occur after severe disturbance) to high (such as occur in long undisturbed or 'old-growth' sites); the current carbon stock at the site level is therefore a direct function of time since last disturbance, and will be quite dynamic temporally. As the spatial scale increases the range between attainable minimum and maximum carbon stocks will become smaller (the minimum will become higher and the maximum lower) due to averaging over many sites at different stages of the disturbance-recovery cycle. At these larger scales the carbon stocks are therefore set by the overall disturbance regime, rather than individual disturbance events.

To implement the concept would require accurate measurements of current carbon stocks across a wide-enough area to cover the full range of site quality variation and disturbance history (as it is the comparison of the aggregated stocks across all such sites,

with the predicted aggregate CCC of those sites, that represents the claimable quantity). There is therefore a barrier in designing and undertaking regional-to-continental sampling strategies within logged forests to ensure unbiased samples with respect to the non-anthropogenic spatial and temporal variability. These sampling problems are similar for a number of land-based mitigation schemes.

The proposed sequestration activity is non-Kyoto compliant, and hence is not currently reportable in the national accounts, and is not being considered as a recognised offset activity under the proposed Australian CPRS. However, it remains to be seen what new policies emerge regarding ecological restoration of natural forest carbon stocks for Annex I countries such as Australia in the post-2012 regime. From a scientific perspective, whatever the international rules, protecting and restoring the carbon stocks of natural forests have the same mitigation benefits for global climate in all countries.

Implementation of the proposal requires a cessation of native forest logging, which would likely generate opposition from the native forest logging industry (but might be beneficial to the plantation industry). In Queensland the intention is to phase out all native forest logging by 2020 (CRA 1999). A key issue that needs to be considered in this context is extending the land-based estimates to include the more comprehensive accounting required to determine the ultimate impact on the atmosphere. This would primarily include the sequestration (and possible fossil fuel substitution) by the harvested products, and additional emissions related to the harvesting practices themselves. Of particular interest to the forest industry are future markets for wood products with a long lifetime (recognising that currently timber products account for just 10% of the harvested roundwood volume) or that can be used to substitute higher GHG emitting products, such as aluminium or steel.

8.5 Compliance and Auditing

The technology exists for estimating the sequestration potential, and involves standard forest biomass and soil sampling techniques, the application of existing forest growth models, and the use of satellite and other aerial imagery. The major current limitations (and opportunities for future research) for the analysis of carbon sequestration potential (CSP) are developing a spatial understanding of (i) historical land use history, particularly harvesting activity, at regional to continental scales; (ii) developing a spatial understanding of historical disturbance history, particularly fire; and (iii) developing a spatial understanding of current carbon stocks across the large areas of Australian eucalypt forest that have undergone historical harvesting.

The estimate of CCC integrates across large spatial (and temporal) scales, and measurements of current carbon stocks are required across commensurate scales. Given the high degree of natural variation across Australia's forest estate, a very large sampling effort would be required to attain satisfactory precision. Statistical power analyses could be used to assess the likely sample sizes required. If it were practically possible to implement such a program, the sequestration estimates of the recovering forests could theoretically be assessed with high precision, so long as permanent monitoring sites were established and maintained, and the fate of those sites recorded through time.

The actual baseline or CCC may shift with future climate change, especially increasing fire risk. For example under significant climate change or altered disturbance regimes there is the potential for altered vegetation composition and structure, with implications for carbon storage.

There is a question of additionality. For example, should it be possible to claim credit for large areas of land that have not been harvested for, say, 40+ years, but through virtue of their tenure *may* be logged in the future? The additionality question arises because it would be necessary to demonstrate that such areas are scheduled for harvesting in the future, i.e. demonstrating that making the decision today to ensure such forests continue recovering their stocks (e.g. by converting their tenure to conservation) leads to an outcome that is different to what would have happened anyway (in the absence of the tenure change). This is particularly relevant for Queensland, where the stated 'business as usual' goal is the cessation of native forest logging by 2020 (CRA 1999).

There may also be a problem of leakage, where timber currently harvested from Australian native forests is sourced, perhaps unsustainably, from elsewhere. However, Australia's plantation estate could potentially provide the required wood product resources (Ajani 2008).

8.6 Other Benefits and Consequences

Conversion of existing native forests that are currently harvested (or eligible for harvesting) to other uses has potential benefits, for example for biodiversity, water catchment, conservation and tourism. This must be weighed up against the economics of ceasing logging, including the possibility of compensation, the cost of implementing and maintaining an appropriate broad scale carbon monitoring program, and the price of carbon. A full economic analysis is required.

8.6.1 Temporal and Spatial Distribution of Mitigation/Sequestration Option

National

- Area = 16.483 million ha x 0.49245 logged = 8.117 million ha.
- Recent (1996-2007) harvested product = 4.89 Mt C/yr.

Assuming a current standing above ground biomass of 146.16 tC/a (40% reduction from Mackey *et al.*'s (2008) CCC total biomass estimate of 289 tC/ha, after assuming 16% of biomass is in the roots), this yields total forest stock of 1.19 Gt C. I.e. recent annual harvested product is around 0.4% of standing stock.

Two scenarios are run (Table 8-1 and Table 8-2). One assuming an average annual harvest rate of 1.3%/yr (to yield the 40% reduction in above-ground biomass, consistent with Mackey *et al.* (2008)) and one with an average annual harvest rate of 0.4% per year. As noted above, this rate results in an average annual harvest of around 10 Mt C/yr. Note the results are expressed on a CO₂-e basis.

Table 8-2: National analysis cessation of logging in 2010.

National Analysis – Mt CO ₂ -e sequestration rates following cessation of logging in 2010		
	Sequestration (Mt CO ₂ -e/yr; living + litter + soil)	
Harvest rate (%/yr)	1.3%/yr	0.4%/yr
Time period		
2010-2015	90.4	19.9
2015-2020	85.5	20.0
2020-2025	80.8	19.9
2025-2030	76.2	19.4
2030-2035	71.6	18.8
2035-2040	67.1	18.0
2040-2045	62.9	17.2
2045-2050	58.8	16.3
2010-2050	74.2	18.7

Table 8-3: National analysis cessation of logging in 2025.

National Analysis – Mt CO ₂ -e sequestration rates following cessation of logging in 2025		
	Sequestration (Mt CO ₂ -e/yr; living + litter + soil)	
Harvest rate (%/yr)	1.3%/yr	0.4%/yr
Time period		
2010-2015	-4.1	-2.3
2015-2020	-3.6	-2.1
2020-2025	16.3	-1.9
2025-2030	91.4	20.3
2030-2035	86.3	20.5
2035-2040	81.6	20.3
2040-2045	76.9	19.9
2045-2050	72.2	19.3
2010-2050	52.1	11.8

Queensland

- Area = 4.475 million ha × 0.824 logged = 3.689 million ha (Table 8-1)
- Recent (1996-2007) harvested product = 0.201 Mt C/yr.

Assuming a current standing above ground biomass of 146.16 tC/ha, this yields a total forest stock of 0.539 Gt C. i.e. recent annual harvested product is around 0.038% of standing stock. This is an order of magnitude less than the national average. However its unlikely Queensland eucalypt forests were historically an order-of-magnitude less intensively logged than others. Therefore in the interests of comparability, the same two scenarios as the national estimates are run, i.e. annual average harvest rates of 1.3%, and 0.4%. Note the results are expressed on a CO₂-e basis.

Table 8-4: Queensland analysis cessation of logging in 2010.

Queensland Analysis – Mt CO ₂ -e sequestration rates following cessation of logging in 2010		
	Sequestration (Mt CO ₂ -e/yr; living + litter + soil)	
Harvest rate (%/yr)	1.3%/yr	0.4%/yr
Time period		
2010-2015	41.1	9.0
2015-2020	38.8	9.1
2020-2025	36.7	9.0
2025-2030	34.6	8.8
2030-2035	32.5	8.5
2035-2040	30.5	8.2
2040-2045	28.6	7.8
2045-2050	26.7	7.4
2010-2050	33.7	8.5

Table 8-5: Cessation of logging in 2025.

Queensland Analysis – Mt CO ₂ -e sequestration rates following cessation of logging in 2025		
	Sequestration (Mt CO ₂ -e/yr; living + litter + soil)	
Harvest rate (%/yr)	1.3%/yr	0.4%/yr
Time period		
2010-2015	-1.9	-1.0
2015-2020	-1.7	-0.9
2020-2025	7.4	-0.9
2025-2030	41.5	9.2
2030-2035	39.2	9.3
2035-2040	37.1	9.2
2040-2045	34.9	9.0
2045-2050	32.8	8.8
2010-2050	23.7	5.3

The net emissions following the cessation of logging show that the system is still losing carbon relative to CCC, but this may or may not be real, as these transient behaviours depend on the historical time course of the logging disturbance. In the above simulations the logging rate is constant each year. If the rate was altered to make the logging more severe early on in the simulation, as is likely, then potentially these number will change (as the forest would already be recovering when the logging perturbation is removed).

Concluding comments

As summarised in the methodology table (Table 8-6) the analyses described here reflect a high degree of underlying uncertainty including: (i) our knowledge of the spatial and temporal patterns of harvesting at regional to continental scales, including the total land area affected by harvesting, the quanta of carbon removed in harvested product, the fate of that product, and the impact on soil carbon and subsequent forest growth dynamics, (ii) the spatial distribution of current carbon stocks, (iii) quantifying regional

differences in species harvested, harvesting methodologies, and historical patterns of land use and disturbance. Current and future research activities that focus on collating and improving these databases will lead to significant improvements over current estimates of carbon sequestration potential at regional, state and continental scales.

8.7 Contributors

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8.8 Research Groups

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8.9 Research Activity and Focus

International studies have demonstrated that harvested forests, through the historical removal of timber for human use, can be significantly depleted in their average carbon stores. For example studies from the USA have estimated eastern hardwood forests to be at approximately 50% of their potential (Brown *et al.* 1997; Houghton and Hackler 2000), and Hurtt *et al.* (2002) have suggested that the currently observed carbon sink across the co-terminous USA forests is caused largely by ecosystem recovery from prior land use, including both agriculture and timber harvesting.

For Australian forests Roxburgh *et al.* (2006) estimated the carbon sequestration potential of *Corymbia* (formally *Eucalyptus maculata*-dominated forests in the Kioloa region of New South Wales, and concluded current above-ground biomass carbon stocks in that region were approximately 40% below their potential. The focus of the Mackey *et al.* (2008) study was primarily to establish current baseline estimates for the carbon carrying capacity of Australian eucalypt forests across a larger spatial domain. They also provided some estimates of the carbon sequestration potential. It is these estimates that were reported in Garnaut (2008).

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Table 8-6: Methodology for Estimating Potential, Attainable and Base Greenhouse Gas Mitigation/Sequestration Opportunities for Pre-1990 Eucalypts.

Option		Retain eucalypt forests (pre-1990) Removal by pre-1990 eucalypt forests
Current or Business as Usual Net Carbon Storage (Mt CO ₂ -e) from 2010 to 2050		The carbon status of Australia's native forestry estate not well known. National GHG accounting assumes net C balance over the long term (includes a balancing assumption of fire loss followed by regrowth). Previously logged forests are likely to be currently a net sink, resulting from regrowth and reduced anthropogenic impacts over the last 30 or so years. Providing these forests are not re-harvested they will continue to accumulate C until CCC is attained. Recent large bushfires also suggest many Australian forests are currently sequestering C as they recover.
Net Potential* Carbon Storage (Mt CO ₂ -e) from 2010 to 2050	Australia	19-74 MtCO ₂ -e/yr assuming a cessation of logging in 2010 (3%-13% of current national emissions). 12-52 MtCO ₂ -e/yr assuming a cessation of logging in 2025 (2%-9% of current national emissions) 47 Mt CO₂-e/yr
	Queensland	8-34 MtCO ₂ -e/yr assuming a cessation of logging in 2010 (5%-20% of current state emissions). 6-24 MtCO ₂ -e/yr assuming a cessation of logging in 2025 (3%-14% of current state emissions). 21 Mt CO₂-e/yr
Functional Unit and Basic Algorithm Used to Calculate per Unit CO ₂ -e		Forest carbon accumulation, on a per ha basis, following the removal of harvesting. Calculations based on a simple dynamic carbon model described in Roxburgh <i>et al.</i> (2006) using the carbon carrying capacity (CCC) estimates of Mackey <i>et al.</i> (2008). Several simplifying assumptions are made in order to generate the sequestration estimates. The numbers therefore have a very high degree of uncertainty.
Scaling Up Process		Spatially averaged estimates of CCC (tC/ha) were applied to total eligible forested areas for both Queensland and nationally, as per Table 8-1. Spatially-explicit modelling, utilising the GIS CCC layer of Mackey <i>et al.</i> (2008) would be an improvement. However a major limitation in the current analysis is the lack of spatially explicit estimates of current carbon stocks (i.e. that include both logging impacts and natural disturbance).

Attainable* Net Carbon Storage (Mt CO₂-e) and factors driving this translation

Base* Net Carbon Storage and factors driving this translation

Previously logged native forests will likely continue sequestering carbon into the future as they regrow, and native forests more generally will continue to store significant carbon, and hence their protection will remain a critical component of the national GHG balance (of course changes to disturbance regimes, particularly fire, pose a significant threat to the national forest estate, but that is a different story...).

The CSP and related concepts were developed as a framework for improving our understanding of C stocks and dynamics in our native forests. Because of the difficulties described in the main body of the text in applying the concept at an operational level (simply because such an application is not what the analysis was intended for), no estimates of 'Attainable' or 'Base' are provided. 'Attainable' could be considered as equal to 'Potential' in the sense that the forest is an existing resource.

The estimates given under 'Net potential storage' for both Queensland and Nationally are an extension of the original values given by Mackey *et al.* (2008) for their study area. Like the Mackey *et al.* (2008) estimate, they provide the first steps towards the quantification of these concepts at large spatial scales.

* See Chapter 1 Section 1.2 Methodology for explanation of potential, attainable and base.

9 Change land use to carbon forestry

Phil Polglase

9.1 Definition and Scope

- Carbon forestry, as defined in this section, is forestry which is not harvested and which would receive payments for carbon sequestration.
- Their location might be anywhere in the landscape – the primary driver being a carbon market. They are differentiated from the National Carbon Bank Plantings which must have a biodiversity outcome as well.
- Carbon forestry could attract permits under the CPRS when established by an accredited forest entity and where plantings meet with the Kyoto eligibility requirements.
- The main GHG gas of concern is carbon dioxide and payments for amounts sequestered. However, there could be other GHG emissions reductions resulting from trees occupying agricultural land, particularly in nitrous oxide due to removal of intensive fertiliser use and in methane from removal of livestock.
- Carbon forestry could potentially offer the opportunity of, once an estate is well established, providing a source of biomass for energy and other products should such markets emerge.

9.2 Analysis Section

Two types of carbon forestry, hardwood plantings and environmental 'woodland' plantings were assessed. In regions greater than 600 mm annual rainfall (deemed to be of least risk and where there is greatest knowledge) an average-weighted, annual rate of carbon sequestration for the two systems over 40 years (2010 to 2050) was estimated to be 12.7 t CO₂ ha⁻¹ yr⁻¹. This was further discounted by an arbitrary 'risk buffer' of 30% to give an annual rate of 9 t CO₂ ha⁻¹ yr⁻¹.

This value of 9 t CO₂ ha⁻¹ yr⁻¹ number can be multiplied by any area deemed suitable, and the number of years of sequestration, to indicate ranges in total carbon sequestration and the potential for carbon forestry to off-set greenhouse gas emissions. Note that the value for area planted is highly uncertain and will depend upon a range of market, social and regulatory factors.

An economic model was used, assuming a carbon price of \$20 t⁻¹ CO₂, to calculate that the total area in Queensland of potentially profitable land was 20 Mha for hardwood plantings, and for environmental plantings was 10 Mha.

With those assumptions, the total amount of carbon sequestered from 2010-2050 across the potentially profitable area was estimated to be 6,120 Mt CO₂, being the weighted average of the hardwood and environmental plantings (Table 9-1). This number can be further discounted by assuming that:

- 50% of the total profitable area is planted, sequestering 3,080 Mt CO₂, and then
- 10% of that area (for example of each farm) is planted in an agroforestry design, giving an amount of 320 Mt CO₂.

Table 9-1: Example scenarios for potential areas and estimated amounts of CO₂-e sequestered for greater than 600 mm rainfall zones. It assumes a mean annual rate of sequestration of 9 t CO₂ ha⁻¹ yr⁻¹. The scenarios serve only to illustrate the range in sequestration potential given certain assumptions.

Scenario	Area (Mha)	Total annual rate of carbon sequestration (Mt CO ₂ -e yr ⁻¹)	Total carbon stored after 40 years (Mt CO ₂ -e)
Total profitable area	17	153	6,120
50% of profitable area	8.5	77	3,080
10% of each farm planted across 50% of the profitable area	0.85	8	310

Carbon plantings can also be targeted to achieve environmental objectives. For example, outputs were 'filtered' to show that, for environmental plantings, 6 Mha were identified that were profitable, intercepted least water and where need for biodiversity plantings was greatest. 2,080 Mt CO₂ were sequestered after 40 years in this scenario.

These estimates have large uncertainties and serve to indicate the magnitude of off-sets by carbon forestry given certain assumptions. The main uncertainties and to which the estimates are highly sensitive include:

- Predicted rates of carbon sequestration (lack of suitable data for some regions and types of carbon plantings)
- Future carbon prices, and
- Land availability, including competition for other land uses and community attitudes.
- The timing of plantation establishment – they cannot all be planted in the one year.

Further research would be very helpful to constrain expected rates of forest carbon sequestration in northern regions, drier zones, a future climate and risks opposed by cyclones, fire, pests and disease.

9.2.1 Background information

The data for this section have been taken substantially from Polglase *et al.* (2008) who developed a large spatial data set (1 km scale) across Australia for estimating the economic and environmental impacts of 10 forestry systems, including carbon forestry. The results from this analysis should be viewed as 'prospecting' for opportunities, in which the aim is to identify regions that may meet the criteria of a particular type of investor; but which requires greater ground-truthing to verify the assumptions used in the model to assess the local social, economic and policy conditions as they pertain to agroforestry developments. The outputs from each carbon planting scenarios represent only one set of assumptions which may vary greatly and thus affect the calculated profitability.

Two types of carbon plantings are considered here:

Hardwood plantations – these would be established and managed as for industrial plantations but are not harvested. We modelled *E. grandis* in the coastal, high rainfall areas and *E. camaldulensis* for the rest of the state. These species were chosen to be indicative only because adequate data were available. In reality other species may be planted.

Environmental 'woodland' plantings – these are usually mixed species, multi-strata trees and shrubs that can be established from tubestock, direct seeding or regenerated from remnant vegetation through, by example, excluding livestock. In some cases, they can be monocultures of local provenances of species. Note that the 3-PG2 model of growth and carbon sequestration could only be calibrated to forests that mature to an open canopy (for which there are most data) and not to closed canopy forests in high rainfall regions.

Methods used to generate the spatial data set included:

Growth modelling for species for which data were available for model calibration and validation and that typically could be grown in the relevant various geo-climatic zones of Australia. A model of forest regrowth and carbon sequestration (3-PG2) was tested against as much data as possible. Results are different from (and usually higher than) the default values generated by the FullCAM model of the DCC.

Economic modelling to calculate spatially the profitability of agroforestry systems, in terms of Net Annual Equivalent Return (NAER, \$ ha⁻¹ yr⁻¹) using discounted cash flow and which includes the opportunity costs of the preceding agricultural enterprise (a profit a full equity layer obtained from ABARE). It included collating information on the economic costs of establishment, management, carbon prices and administrative costs associated with carbon trading.

Environmental impacts of carbon plantings on: (i) biodiversity using a 'nearest-neighbourhood' analysis developed for the project in collaboration with Richard Thackway (BRS) and David Freudenberger (Greening Australia), and (ii) water interception (compared to grassland). The spatial data set was then interrogated to identify areas where profitability coincided with biodiversity need and least water impact.

The resulting spatial layers were then used to:

- Identify all areas that were potentially profitable (in comparison to existing agricultural land use), and
- Calculate the total amount of carbon sequestered across this area, averaged for the first 20 years of growth. Results were then adjusted for 40 years of growth (2010-2050).

The total area identified as being potentially profitable (Table 9-2) represents a theoretical maximum and assumes that all the land identified as being suitable is planted. In reality, the total area available for planting is much less, because: (i) not all the land would have been cleared prior to 1990, (ii) not all the land would be available, properties being held for conventional agricultural enterprises and other changes in land use, and (iii) for any given property it will often be the case that only a proportion of the land would be established to carbon forestry.

Results can therefore be adjusted downwards from the theoretical maximum using revised assumptions to indicate plausible ranges in areas planted and rates of sequestration.

Table 9-2: Summary of economically viable areas (Net Annual Equivalent Return > \$0) and rates of carbon sequestration over 20 years for two types of carbon plantings. NAER is the estimated profitability taking into account the opportunity costs of the preceding agricultural land. Numbers in brackets are carbon sequestration rates adjusted for a 40-year period.

	Area (Mha)	Total annual rate of carbon sequestration (Mt CO ₂ -e yr ⁻¹)	Average areal rate of carbon sequestration (t CO ₂ -e ha ⁻¹ yr ⁻¹)
Hardwood plantings	20	405	20 (15)
Environmental plantings	10	96	10 (8)

Hardwood carbon plantings were predicted to have higher rates of carbon sequestration (Figure 9-1 and Figure 9-2), and hence were more profitable (Figure 9-3 and Figure 9-4) than environmental plantings. The difference may be real but needs to be treated with caution. The growth data set for environmental plantings was the most variable of all the species and systems examined, being a combination of different types of plantings (mixed species, monoculture) and establishment techniques (tubestock, direct seeded, natural regeneration). It may be expected that rates of growth are somewhat less than plantation systems, especially for multi-species systems that are direct seeded or naturally regenerated and which may be subject to competition between individual plantings when established at close stocking. In contrast, plantations are established using genetically improved stock, are kept at an appropriate stocking to limit competition and have good weed and nutritional management.

Model calibrations and validations were excellent for hardwood plantations, including for *E. grandis* growing in the high rainfall, coastal zone. However, predictions from northern Australia for hardwood species are highly uncertain because of a lack of data against which to calibrate the model.

Figure 9-3 and Figure 9-4 show the spatial distributions of all areas assessed as being profitable. Only land that is privately-owned agriculture and non-forested is considered. For hardwood plantings, most of the available land area was assessed as being potentially profitable and had a NAER > \$150 ha⁻¹ yr⁻¹. For environmental plantings there were fewer areas and nearly all had a NAER < \$150 ha⁻¹ yr⁻¹. These scenarios were for a carbon price of \$20 t⁻¹ CO₂-e. If the price is increased, to \$20 t⁻¹ CO₂-e for example, the potential area of profitability is also increased and the estimated NAER is higher on average.

Table 9-3 shows the results for a recent ABARE analysis of opportunities for environmental carbon plantings. Their methods were similar to those undertaken by Polglase *et al.* (2008). They used default values for rates of carbon sequestration, over 43 years (2007-2050), provided by the NCAT to calculate economically viable areas to 2050 under two different carbon prices.

Table 9-3: Summary of economically viable areas for environmental plantings and rates of carbon sequestration over 43 years (Lawson *et al.* 2008).

Carbon price (\$ t ⁻¹ CO ₂)	Area (M ha)	Total annual rate of carbon sequestration (Mt CO ₂ -e yr ⁻¹)	Average areal rate of carbon sequestration (t CO ₂ -e ha ⁻¹ yr ⁻¹)
20.9	1.53	4.66	3.1
29.1	10.6	21.4	2.0

The results show that the economic viability of environmental plantings is very sensitive to carbon price, as was also demonstrated by Polglase *et al.* (2008) using uncertainty analysis. The rates of carbon sequestration averaged about 2.5 t CO₂-e ha⁻¹ yr⁻¹ for the 43-year period, substantially lower than the 10 t CO₂-e ha⁻¹ yr⁻¹ calculated by Polglase *et al.* (2008) in Table 9-2 over 20 years and for rainfall > 600 mm/yr. The difference is not entirely inconsistent. When the 20-year value (10) is extrapolated to 43 years it is less (8) because rates of carbon sequestration decrease as forests age. And it could be further discounted to apply a 'risk buffer' that would take into account cycles of death and decay and possible loss of forest by fire, pests, disease or storms (see discussion under 'Compliance and auditing').

The spatial outputs from Figure 9-3 and Figure 9-4 can be further constrained using the Scenario Planning and Investment Framework tool (<http://www.csiro.au/resources/SPIF.html>) developed previously under a large program of research (Commercial Environmental Forestry) to identify regions suitable for agroforestry systems against various criteria for economic and environmental outcomes including relatively low negative water interception impact and high positive biodiversity impact. The purpose here is to illustrate the methodology and types of outputs that can be generated rather than to indicate where carbon forestry should be established. The criteria used as an example to constrain potential planting areas were: NAER > \$0 ha⁻¹ yr⁻¹, water interception < 150 mm yr⁻¹, Biodiversity score < 50 units.

The results (Figure 9-5 and Figure 9-6) show that considerable areas were identified as being profitable (above the agricultural land use) and where objectives of biodiversity enhancement and least water impact could be met. The difference between hardwood and environmental plantings was less than if the whole of Qld was considered.

There are also opportunities to establish carbon farms on indigenous lands (Figure 7-1) although they may not meet Kyoto requirements and thus may not be eligible to participate in the CPRS. In that case, participation in voluntary markets may be an option.

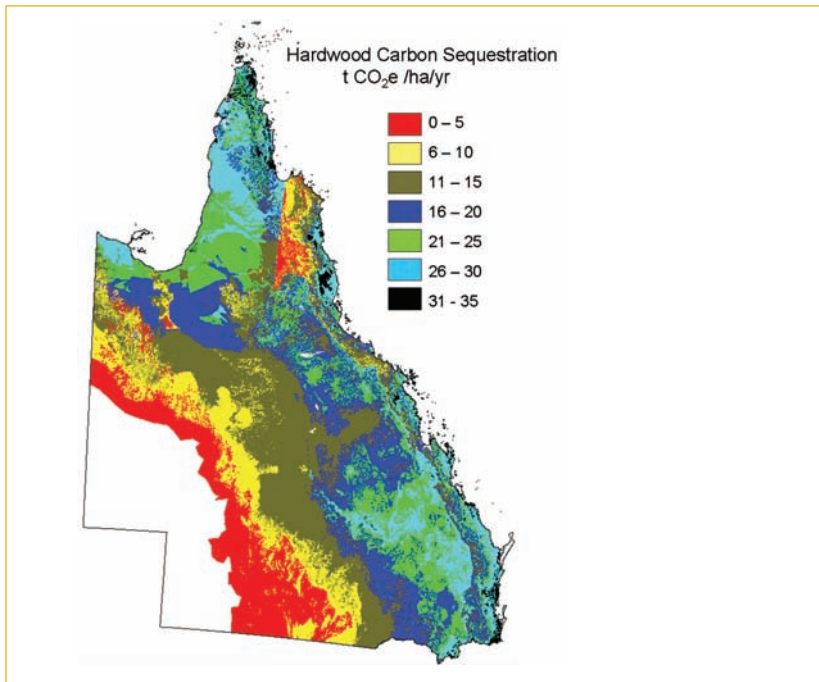


Figure 9-1: Predicted rates of CO₂ sequestration in live biomass (above and below ground) after 20 years age for hardwood plantations of *E. grandis* (coastal tropical zone) or *E. camaldulensis* (all other areas).

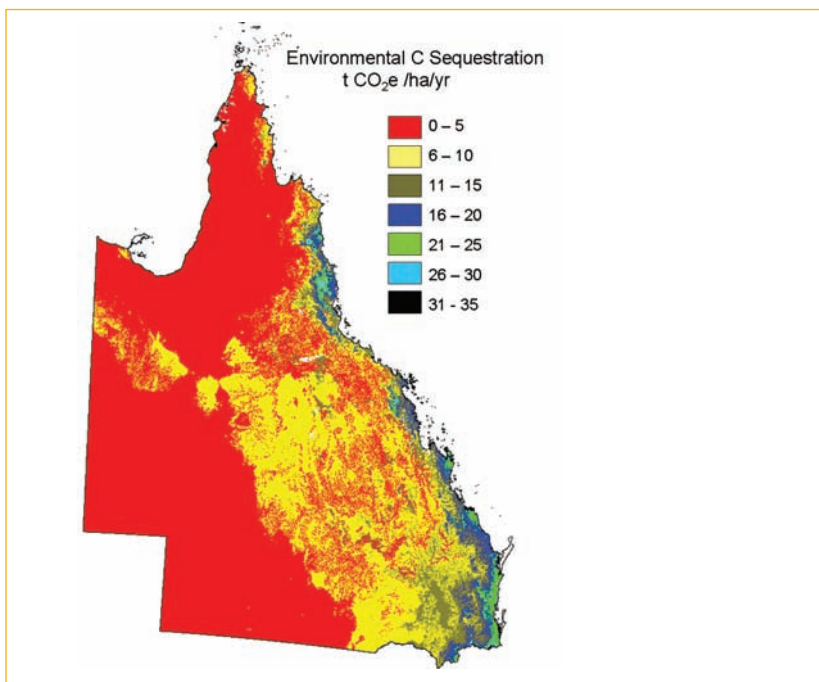


Figure 9-2: Predicted rates of CO₂ sequestration in live biomass (above- and below-ground) after 20 years age for environmental plantings.

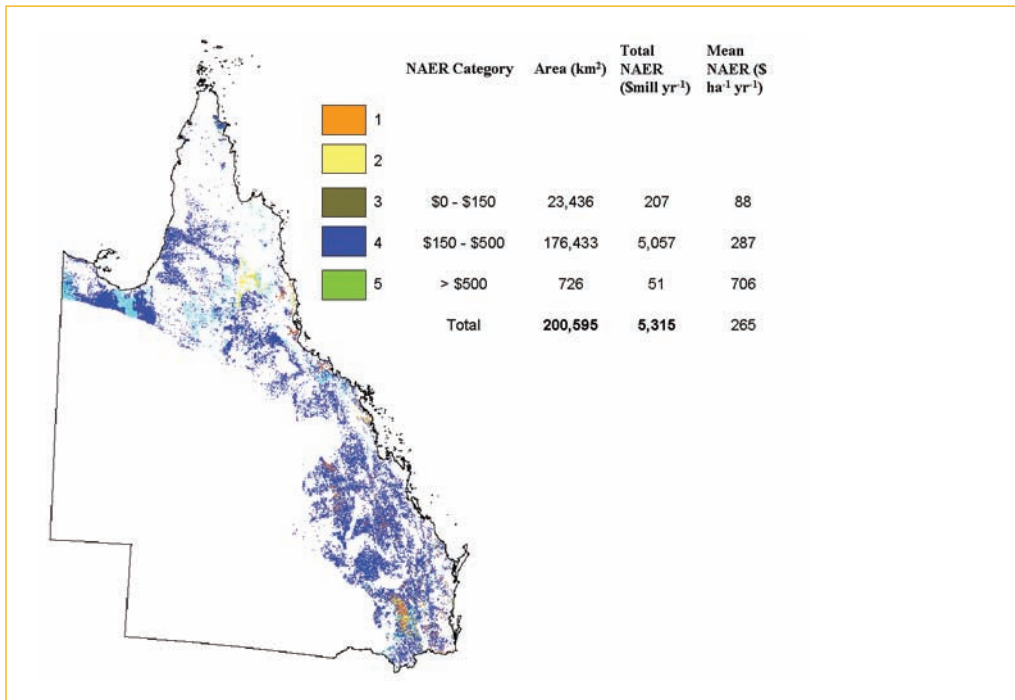


Figure 9-3: Map of economically viable areas (Net Annual Equivalent Return > \$0) for hardwood plantings at a carbon price of \$20 t-1 CO₂-e in > 600 mm rainfall zones. NAER is the estimated profitability taking into account the opportunity costs of the preceding agricultural land. Classes 1 (orange) and 2 (yellow) are negative NAER values.

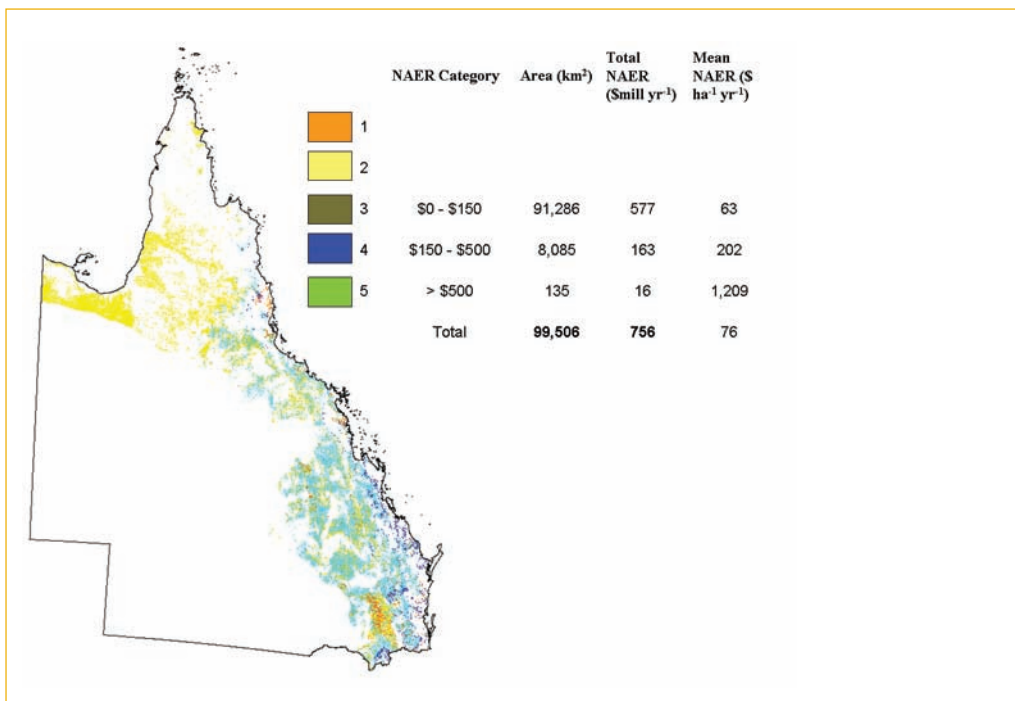


Figure 9-4: Map of economically viable areas (Net Annual Equivalent Return > \$0) for environmental plantings at a carbon price of \$20 t-1 CO₂-e in > 600 mm rainfall zones. NAER is the estimated profitability taking into account the opportunity costs of the preceding agricultural land. Classes 1 (orange) and 2 (yellow) are negative NAER values.

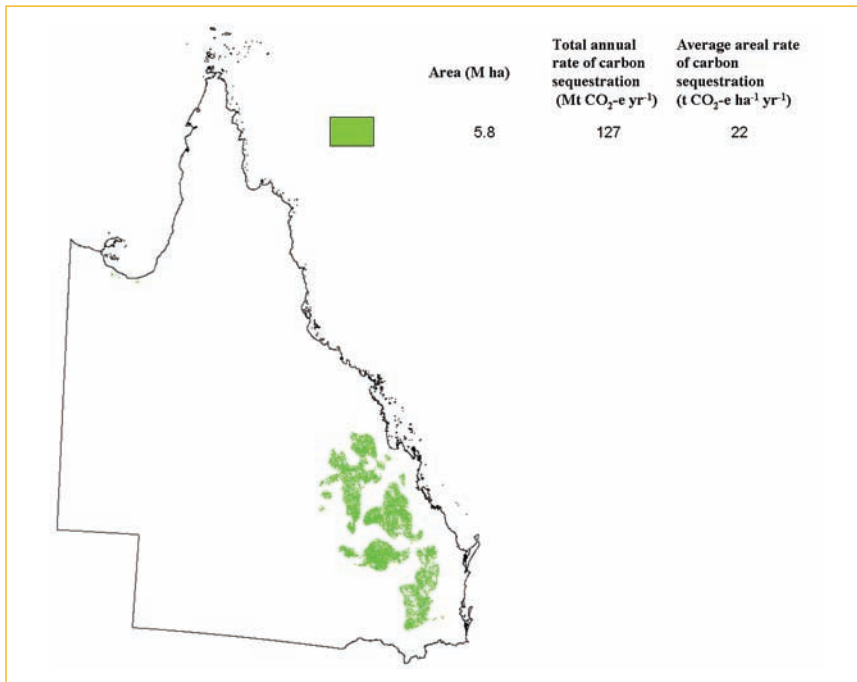


Figure 9-5: Map of all areas for hardwood plantings in > 600 mm rainfall zones that meet the multiple criteria of being profitable, intercept least amount of water compared to grassland, and biodiversity need is greatest (NAER > \$0, water interception < 150 mm/yr and biodiversity score < 50 units).

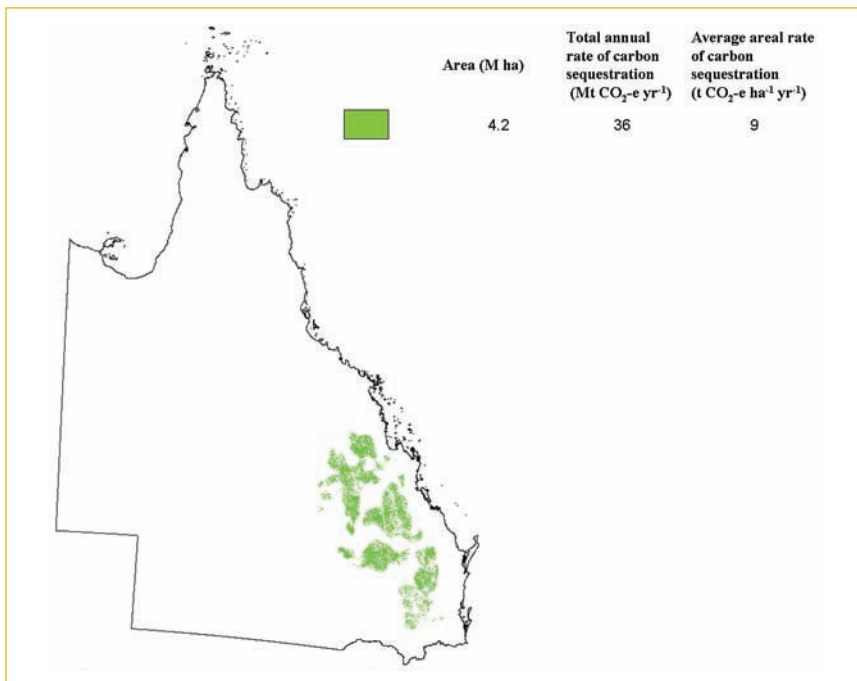


Figure 9-6: Map of all areas for environmental plantings in > 600 mm rainfall zones that meet the multiple criteria of being profitable, intercept least amount of water compared to grassland, and biodiversity need is greatest (NAER > \$0, water interception < 150 mm/yr and biodiversity score < 50 units).

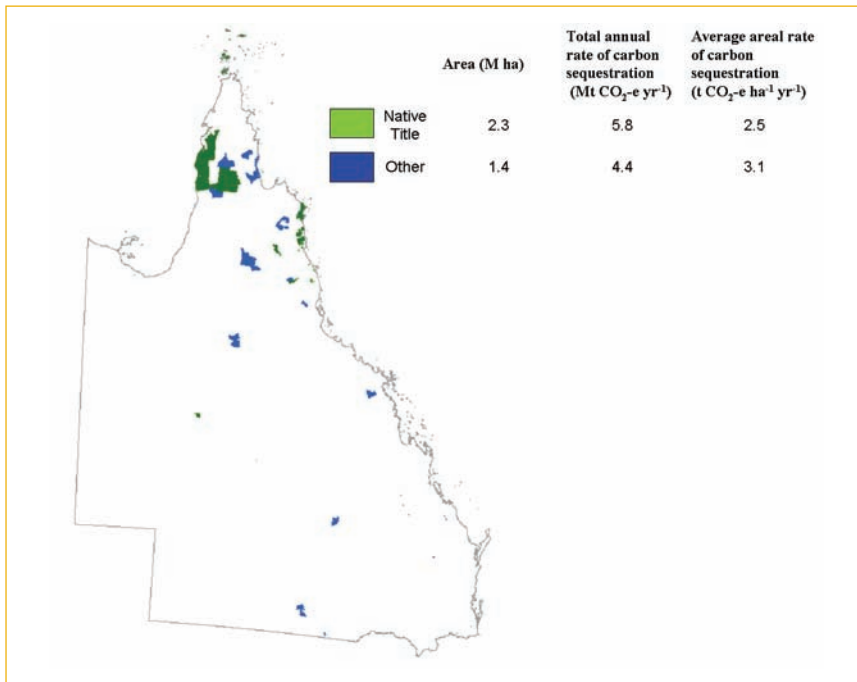


Figure 9-7: Indigenous areas in Qld and total carbon sequestration for environmental plantings. Note that, due to lack of data, many of these model estimates such as in native title areas are uncertain and outside the areas for which the model was calibrated.

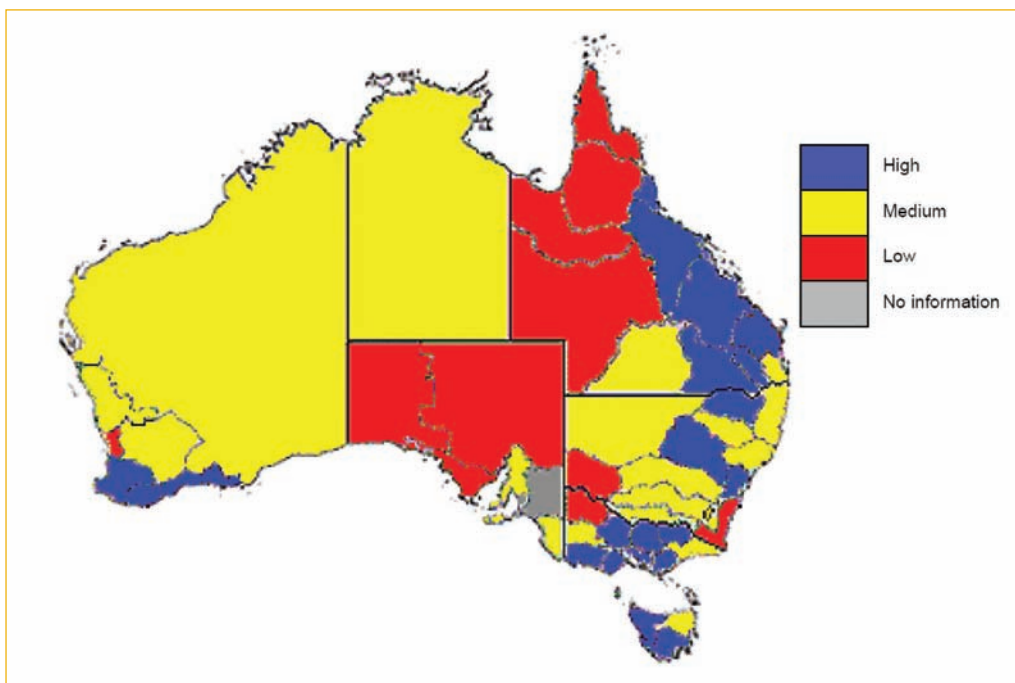


Figure 9-8: Interest in agroforestry across the 57 NRM regions of Australia.

The capacity to establish new forests may depend as much on social attitudes and the acceptability of integrating trees into agricultural landscapes, as it does on biophysical and economic assessment of plantation potential. Polglase *et al.* (2008) reviewed the published Investment Plans for the 57 NRM Regions (mostly CMAs) in Australia for their interest in agroforestry. The results (Figure 9-8) show that NRM regions in the south-east of Qld were rated as 'High' for their interest in agroforestry and which coincided with the areas identified as potentially profitable (Figure 9-4).

The default accounting tool under the CPRS is likely to be NCAT. Although this tool has been well calibrated to potential above-ground biomass it has yet to be calibrated for earlier growth rates of these plantings on ex-farmland. Consequently, Polglase *et al.* (2008) collated data sets to calibrate the 3-PG2 model. It is expected NCAT defaults will be available for the initial stages of growth for environmental plantings in due course. Figure 9-9 compares outputs from the two models for 20 randomly sites across Queensland. The relationship is linear, as would be expected, but for many sites 3-PG2 predictions are higher than the NCAT. There will obviously be errors in both models. As discussed previously, if a risk buffer was applied to the 3-PG2 predictions, then the outputs from the two methods would converge.

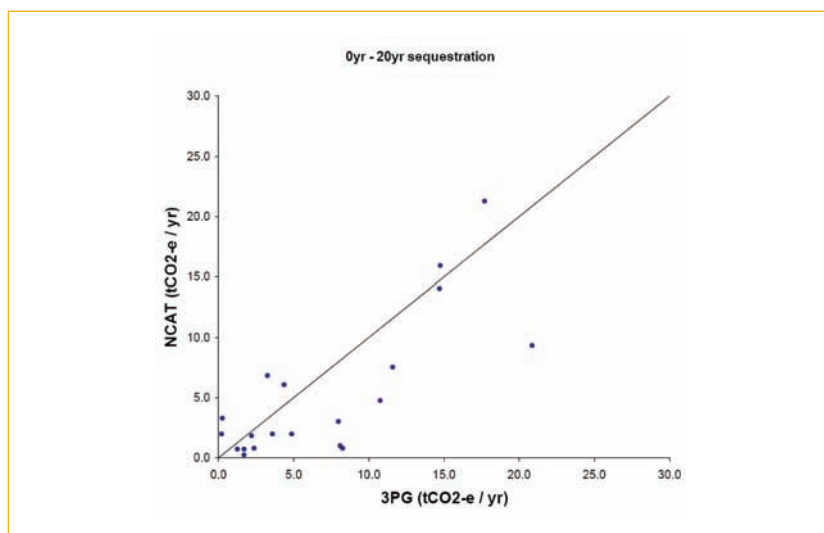


Figure 9-9: Comparison of rates of carbon sequestration after 20 years from 3-PG2 and NCAT models for 20 randomly located sites in Qld.

9.3 Defining Uncertainty

9.3.1 Uncertainty in estimates

Polglase *et al.* (2008) undertook uncertainty and sensitivity for limited agroforestry systems to demonstrate the methodology and identify those variables that most affected profitability. Monte Carlo analysis was used to run economic models 10,000 times while varying the range of input parameters. Here, we discuss the main factors (economic, biophysical, social) which affect future estimates of forest establishment and carbon sequestration in Queensland.

The main sources of uncertainty and which are common to many afforestation activities include:

Economics: The uncertainty and sensitivity analysis of Polglase *et al.* (2008) showed that (unsurprisingly) the profitability of carbon forestry is determined primarily by: (i) growth rate, and (ii) the price of carbon, which was assumed to be \$20 t⁻¹ CO₂-e and is expected to rise in the future. Land values would also be expected to be important but were not part of the analysis. Some large-scale plantation developments could incur a cost for the amount of water they intercept. We did not include this in our calculations of NAER but it is likely to make a substantial difference to the economic outcome for those plantations required to purchase water access entitlements.

Prediction of rates of carbon sequestration: The predictions of growth presented here were the best available at the time. For the hardwood species, the model calibrations and independent validations were reasonably good. However, there were few data for plantations in northern Australia. Given the hot, humid, and seasonally wet climate there, predictions include an uncertainty associated with not including impacts of pests, disease and other distance on growth.

For environmental plantings there were few data for closed canopy forests and so the model was calibrated more to the open woodland condition. The data set for environmental plantings was also highly variable and model calibrations and validations were the worst of all the forestry systems and species we tested.

Risks posed by fire, storms, pests, disease and other disturbances: Carbon needs to be stored for a prescribed time in trees. If it is lost then the carbon needs to be paid back, and if the price of carbon rises over time then disturbances to forest plantings pose a serious risk. In Qld there are numerous threats to forests and which make long-term predictions difficult. In the hotter, humid environments the risks posed by pests and disease increase.

Climate change impacts: Climate change has at least two important implications for carbon forestry. It may change the future conditions under which trees will grow. For example, a site planted to a particular trees species may not favour that same species after 50 years. Climate change may also affect predicted rates of growth due to changes in rainfall, temperature and CO₂. Productivity may be substantially increased or decreased, depending upon the photosynthetic response of trees to increased concentrations of atmospheric CO₂ (for example, Battaglia *et al.* 2008).

Climate change may shift the baseline for agricultural production and on which land might be deemed suitable for afforestation. For example, land might be economically unviable for carbon forestry in the present climatic and economic environment, but would become suitable in decades ahead in a changed climate.

Availability of land: It is important to differentiate between the area of land that is assessed as being potentially profitable (according to the assumptions used) and the land that is realistically available and that could be planted. Estimates for areas of forest establishment therefore include (from highest to lowest values):

- The total area of land available for planting (land that is Kyoto compliant).
- The total area assessed as being profitable (for example, and Figure 9-4).
- The area of land (number of farms) that would be available for planting (depending upon competing land uses, farmer and community attitudes, and current and future regulations governing land use change).
- The proportion of each farm that would be planted (for some off-set companies or other private investors this might be 10% of the farm for example).

Furthermore, there could be plantings targeted at meeting NRM objectives, and which would constrain plantings as illustrated in Figure 9-5 and Figure 9-6 .

Timing of establishment: Not all the forests would be established in the one year. The calculations here assume an average rate of carbon sequestration over 40 years, implying that all the trees would be planted in 2010. In reality, trees will be established progressively over time.

Investor interest: There are many different types of investors, ranging from farmers and land holders, institutional companies, traditional forestry companies, carbon offset companies and Governments. Our analyses considered only broad economic costs and returns to the landholder and third-party investor. It was not a financial model and thus did not attempt to identify specific opportunities for companies, each of which will have their own business model and financial structure. It is clear from experience to date that off-set companies do not necessarily compete for the same land. Predicting where future plantings will go is therefore difficult and many of the commercial companies would not declare the regions in which they are interested in purchasing or leasing land.

Net impacts on environmental values: Biodiversity and water impacts were chosen as two of the major issues of concern. Biodiversity can be measured across different scales of time and space. The beneficial impacts can be localised or regional. They can be specific to some particular species or they can provide general restoration of habitat. Biodiversity enhancement may be the main driver of afforestation with a carbon market funding establishment.

Large-scale afforestation may be subject to water licensing in catchments that are over-allocated or approaching full allocation. Polglase and Benyon (2009) reviewed some of the issues relevant to plantations and water security across Australia and developed a data base that enabled the impacts of plantations on water availability to other users to be assessed in each of the Surface Water Management Areas of Australia. The recent Sustainable Yields Project (CSIRO 2008) has assessed water availability issues in each catchment of the Murray Darling Basin and provides a reference point for assessing whether land use change is likely to be significant or not. The 'Zhang curves' (Zhang *et al.* 2001) used here are generalisations only of the amounts of water intercepted compared with grassland that otherwise would result in stream flow.

Community attitudes: The extent to which plantings are established may depend upon social attitudes as much as anything else. Our review (Figure 9-8) suggests that Qld NRM regions are relatively supportive of agroforestry type systems.

9.3.2 What can be done to further constrain uncertainties?

There are at least three main activities that can refine and further constrain estimates:

- Collate more data on carbon sequestration for Qld tree species and systems for model calibrations. Particular needs are for environmental plantings and species in northern Australia.
- Ground truth and test areas identified as prospective opportunities. This could include for example, answering such questions as: Is the land available? Is it suitable? What are the social attitudes? What are the expected growth rates; are there any local trials and data to verify model predictions? Any there any potential impacts on water and biodiversity?

- Re-run economic analyses using different input assumptions. A large spatial data base has been collated, with a user-friendly interface that can be used to re-run scenarios using revised assumptions for rates of carbon sequestration, project costs and product prices. It can be undertaken for all forestry systems including carbon forestry, industrial sawlog and pulpwood systems and energy plantings.

9.4 Risk and Barriers to Implementation

Many of the main risks and barriers to implementation have already been discussed. The three main ones include:

- Uncertainties in financial viability, especially due to incomplete knowledge of growth rates and future climatic and associated risks.
- Land availability and cost. This includes competition for land by conventional and future agricultural enterprises.
- Social attitudes. Some people and communities like trees on farm land, others passionately do not.

9.5 Compliance and Auditing

Carbon forestry offers a (relatively) straightforward way to participate in a carbon market. They are eligible, effective, achievable and verifiable. The details of how forestry and off-sets might participate in a CPRS are yet to be determined but some of the pertinent points include:

- Reforestation and afforestation are eligible to participate in the proposed CPRS. They would have to meet requirements consistent with Article 3.3 of the Kyoto Protocol; for example, forests would need to be established on agricultural land that had been cleared prior to 1990.
- To meet requirements of permanence, forests will need to be managed (and the carbon counted) according to natural cycles of death and decay. A common rejoinder that one hears in opposition to use of forests as carbon off-sets is that 'the trees will get burnt at some stage'. The implication is that if trees are not burnt or otherwise disturbed then they somehow live forever. It also ignores the fact that disturbances are often required for regeneration of natural forests. The long-term aim might be to manage forests of a range of ages, the amount of carbon registered being an average of old and young forest, and not the maximum possible for any given hectare.
- DCC and the NCAT would provide default prediction for amounts of carbon sequestered.
- There is a need for measured amounts of carbon sequestered every five years but it could be on shorter scales if it was financially advantageous.
- Monitoring and auditing is relatively straightforward for most afforestation projects.
- It is generally safe and easiest to assume that changes in soil carbon after afforestation are negligible. However, changes may be as large as those due to change in agricultural management. Thus, there may be implications if the agricultural sector is eventually included in a CPRS.

9.6 Other Benefits and Consequences

- Carbon forestry is potentially an attractive investment because, compared with industrial plantations, the product (CO₂) remains in the tree, thus avoiding costs associated with harvest and transport and which can be up to about 50% of the total.
- Because carbon plantings do not need to be close to processing facilities they can be dispersed across the landscape. This:
 - reduces the risk from individual events that might release carbon, such as from drought, fire, pests and storms, and
 - Can mitigate the impacts on water availability by:
 - selecting catchments where there would be little water impact on consumptive users and environmental flows, and
 - not having large, concentrated and contiguous blocks that can impact upon local down-stream users, if not on regional water flows.
- The market size is 'infinite' in the sense that it is not constrained by market demand. This contrasts with harvested plantations, the area of which is constrained by demand for products and processing capacity, and which need to be located near processing facilities.
- The forests can be located and designed to maximise positive environmental outcomes and minimise the trade-offs.
- Some practitioners and business models are integrating trees into farm land as part of a mixed agricultural enterprise. Typically, the trees are planted on say 10% of the farm and used for shelter for livestock, wind breaks, localised salinity mitigation, biodiversity benefit and amenity value for capital appreciation.
- Once the trees are established they could be used for other products. However, as the CPRS White Paper points out, if the price of carbon increases over time then harvesting at a later stage could incur higher financial penalties compared with leaving the carbon stored in trees.

9.7 Lateral Thinking

Establish forests in the first instance to get sequestration and other benefits and to get a crop in the ground. That provides the option of harvesting some of the estate later on for emerging markets, depending upon economics.

9.8 Contributors

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- Brian McCormack Forestry Plantations Qld

9.9 Research Groups

- Australian Government Department of Climate Change. (This includes the National Carbon Accounting System which is proposed to be the default method for crediting carbon sequestration)
- CRC-Forestry. This is collating data and calibrating models of growth for mostly hardwood species in new environments of Queensland.
- Queensland Department of Employment, Economic Development and Innovation (Who are also contributing to the above research in CRC -Forestry)
- CSIRO Agricultural Sustainability Initiative who have mapped prospective areas of opportunity for forestry plantings across Australia at 1 km scale, including rates of carbon sequestration, economics and impacts on water and biodiversity.
- Australian Bureau of Agricultural Resource Economics. (ABARE has also estimated economically viable areas in each State and Territory for industrial plantations and environmental plantings).

9.10 References

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Table 9-4: Methodology for estimating potential, attainable and base greenhouse gas sequestration/mitigation for carbon forestry plantations.

Option		Change land use to carbon plantings <i>Carbon Forestry</i>
Current or Business as Usual Net Carbon Storage (Mt CO ₂ -e) from 2010 to 2050		No data for the extent of carbon plantings in Qld, but they are currently small in area.
Net Potential* Carbon Storage (Mt CO ₂ -e) from 2010 to 2050	Australia	The average is 30,000 Mt CO ₂ -e. It includes a 30% discount for a 'risk buffer'. 750 Mt/yr
	Queensland	Assuming a carbon price of \$20 t ⁻¹ CO ₂ , the area of economically viable land is 20 Mha for hardwood plantings with a total carbon storage of about 8,400 Mt CO ₂ -e which includes a 30% discount for a 'risk buffer'. If a part of this is made available for environmental plantings, with an area of 10 Mha, carbon storage would be 2240 Mt CO ₂ -e (56 Mt CO ₂ -e/yr) which includes a 30% discount for a 'risk buffer'. It is assumed that the final planted area will be a mix of these two types. This brings the average down to 6,120 Mt CO ₂ -e over 40 years (153 Mt CO ₂ -e/yr) which includes a 30% discount for a 'risk buffer'. Values may be higher as the carbon price increases. 153 Mt/yr
Functional Unit and Basic Algorithm Used to Calculate per Unit CO ₂ -e		Functional unit is t CO ₂ -e ha ⁻¹ yr ⁻¹ . Assume an average rate of carbon sequestration of 9 t CO ₂ -e ha ⁻¹ yr ⁻¹ for carbon forestry over 40 years which comprises an average of hardwood and environmental plantings on an area weighted basis, includes a decrease in rate from 20 to 40 years, and a discount of 30% as a risk buffer for disturbances.
Scaling Up Process		The average rate of sequestration over 40 years (9 t CO ₂ -e ha ⁻¹ yr ⁻¹ is multiplied by the area of land planted (17Mha) (and the number of years) There may be additional emission reductions from displacing livestock and other agricultural use. Area to be planted is most uncertain and involves assumptions about policy regulation, productivity, the opportunity cost of converting from Agricultural land, and how both of these may change under climate change.
Attainable* Net Carbon Storage (Mt CO ₂ -e) and factors driving this translation	Queensland	3,080 Mt CO ₂ -e over 40 years Assume that 50% of the total available land is planted. 77 Mt/yr
Base* Net Carbon Storage (Mt CO ₂ -e) and factors driving this translation	Queensland	310 Mt CO ₂ -e over 40 years Assume that 10% of each available farm was planted. 8 Mt/yr

See Chapter 1 Section 1.2 Methodology for explanation of potential, attainable and base.

10 Substitution of fossil fuels with bioenergy from renewable biomass resources

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10.1 Definition and scope

The term “bioenergy” included liquid biofuel, bioelectricity and heat. There are many different technological pathways for producing bioenergy, as well as bioproducts (such as biochar) from biomass.

The various production pathways can be broadly grouped into:

- First generation technology - this means that it is currently industrially applicable (i.e. already a commercial enterprise). This generally includes fermentation of sugar and starch crops to ethanol, or transesterification of plant and animal oils to biodiesel.
- Second generation technology - this represents a step change in technology; it has been physically demonstrated but is not yet commercial due to scale-up issues, or it is not commercially viable due to very high conversion costs. There are several different types of biochemical or thermo-chemical transformation processes that can use non-edible fibrous or woody portions of plants (called lignocellulose) to produce biofuel and bioelectricity, separately or together. There are also opportunities being investigated to use algae to produce biodiesel.
- Third generation technology - this means that the process is at the conceptual planning stage, ‘on drawing board’ or at benchtop demonstration stage, but has a long way to go before it can be deployed. Many of the processes which could be used to make biofuels and bioelectricity are not commercially viable and may rely on high value coproducts such as bioproducts for profitability (as oil relies partially on its petrochemical coproducts to remain profitable). There are many sorts of biorefineries which could be designed to run integrated processes and multiple coproducts.

Each of these different technologies has close links to the types of biomass that can be used to feed the process (known as biomass feedstocks). In addition to the types of technologies and feedstocks, assessments must be made in relation to the current production base for biomass (i.e. what is already being produced in Australia) as well as future production base (which may include new and novel plant species, or changes in land use to produce energy crops or forests etc). These are shown in Table 10-1.

Table 10-1: Feedstocks and conversion technologies for biofuels, bioelectricity and bioproducts. Feedstocks addressed in this report are marked with an asterisk. These represent the subset of the potential feedstocks for which at least some reliable data were readily available for this study. Adapted from O'Connell et al. (2007a).

	First generation biofuels	Second generation biofuels and bioelectricity	Third generation biorefineries
Current production base	<ul style="list-style-type: none"> • Sugar and starch crops* • Oilseed crops* • Tallow 	<ul style="list-style-type: none"> • Crop residues (sugar, cereal) • Existing agricultural or rangeland grasses • Farm forestry • Plantation forestry — pulplogs, thinnings, harvest residues* • Native forest wood and residues • Wood waste in landfill* • Other waste streams (e.g. agricultural processing residues, green waste) 	Integrated processing <ul style="list-style-type: none"> • Food • Feed • Fibre • Electricity • first gen fuels • New gen fuels • High value bioproducts as petrochemical replacements • No 'waste' New/rearranged value chains => bioeconomy
Future production base	<ul style="list-style-type: none"> • Expanded (more area, improved yield) or reduced area (due to climate change) current agricultural production base* • GM crops • Novel energy crops e.g. <i>Pongamia, Jatropha, Agave</i> 	<ul style="list-style-type: none"> • Expanded (more area, improved yield) or reduced area (due to climate change) current agricultural production base* • GM crops • Novel energy crops e.g. <i>Pongamia, Jatropha, Agave</i> • Algae 	

Different fractions of the plant can be used with different technologies. For example, in the case of a cereal crop using first generation technology, ethanol is produced only from the grain and competes directly with human food and animal feed markets. With the advent of second generation technologies however, the stalks or stubble from the grain could be diverted away from the current system of being retained in a minimum tillage system (or in some areas being burnt), to being:

- Co-fired in a coal fired power station to produce bioelectricity.
- Converted into ethanol via enzymatic technologies.
- Converted directly into syndiesel and syngasoline or biocrude using thermo-chemical processes.
- Converted by pyrolysis into biochar and syngas (which could be used to produce syndiesel or run a turbine for bioelectricity).
- In future, being fed into a biorefinery to make a range of bioproducts (e.g. bio-plastics, adhesives) as well as energy or fuel as a coproduct (Haritos 2007).

There will be negative consequences of removing the stubble for bioenergy compared to leaving it *in situ* – however, the specific trade-offs between offsetting fossil fuel, compared to retaining the stubble *in situ* have yet to be determined in detail (Dunlop et al. 2008).

There are multiple pathways to biofuel and bioelectricity production, depending on the feedstock types, conversion technologies and combustion methods. These pathways can have vastly different greenhouse gas (GHG) emissions, depending on which biomass feedstocks are used, how they were produced (high inputs lead to higher GHG emissions), which technology is used to transform the fuels, the distance transported, and how they are combusted. A small subset of options, largely based on the ready availability of data to support the analysis, was used in this study. They were grouped into a defined set of feedstock and technology scenarios for:

- first generation biofuel
- second generation biofuel
- bioelectricity

10.2 Analysis section

10.2.1 Scope of scenarios investigated

There are many combinations of diverting current biomass production, expansion of current production systems, new and novel species and production systems as well as conversion pathways that could be explored in this type of analysis. For the current purpose of exploring the magnitudes of potential mitigation, we have used some simple combinations of current and future production systems with first and second generation technologies. Each new generation of biofuel and bioelectricity technology represents a step change not only in the technology, but also in the magnitude of opportunities, timeframes, economics and levels of uncertainty. They have thus been handled separately in this report.

Table 10-2: Feedstock and technology summations.

First generation biofuels				
	Feedstocks	Product	Current/future production base	Analyses
Sugar and starch crops	Sugar C-Molasses Cereal grain	Ethanol	Current, with future production trajectories estimated separately for each biomass source	Summed to give First Generation Biofuels
Oils	Oilseed crops	Biodiesel	Current, with future production trajectories estimated separately for each biomass source	
Second generation biofuels and bioelectricity				
Lignocellulose	Cereal stubble Wood waste Bagasse Sawmill residue Harvest residue Pulpwood	Fischer-Tropsch syndiesel+ syngasoline + bioelectricity	Current, with future production trajectories estimated separately for each biomass source	Summed to give Fischer-Tropsch syndiesel + syngasoline + electricity
Lignocellulose	Bioenergy plantations	Fischer-Tropsch syndiesel+ syngasoline + bioelectricity	Future production trajectories estimated	
Oils	Algae	Biodiesel+ bioelectricity	Future production trajectories estimated	
Bioelectricity				
	Cereal stubble Wood waste Bagasse Sawmill residue Harvest residue Pulpwood Bioenergy Plantations	Bioelectricity	Current, with future production trajectories estimated separately for each biomass source	Summed to give bioelectricity

10.2.2 Methods

A simple model was constructed in Microsoft Excel™, to collate data and assess first generation and second generation biofuels, and bioelectricity. Several simple arithmetic calculations were used to:

- Collate production statistics to estimate feedstock land areas and yields for each current feedstock type, for each scenario.
- Estimate future feedstock land areas and yields using expansion/contraction of current feedstock production areas, or other means for new feedstocks (short rotation forestry and algae).
- Estimate the production emissions for each current and future feedstock type.
- Estimate transport emissions for each current and future feedstock type.
- Divert a proportion of each feedstock in each scenario.
- Collate published or unpublished data on feedstock conversion coefficients L/t or MWh/t), and associated conversion emissions for each feedstock type.

- Collate data on emissions for each fuel or energy source that will be displaced by the feedstock/conversion technology combination and calculate the mitigation of an equivalent unit of each biofuel or bioelectricity (L or MWh), based on the energy density ratio of each fuel.
- For each technology type (first generation biofuels, second generation biofuels, bioelectricity) sum the mitigated emissions for the proportion of diverted feedstocks in each scenario ('Business as Usual', 'Maximum Potential' and 'Attainable').

10.2.3 Current biomass production base – land areas, yields, emissions

Although statistics are collected about current commodities being produced (e.g. grain, sugar, pulpwood, sawlogs), other fractions of the total biomass are not measured and must be estimated from the basic production statistics. Some of these commodities and the remaining biomass could potentially be used for production of bioenergy or liquid biofuel given the right economic conditions. For example, some sawmill residue is sold as woodchips, garden products, or used to provide heat or power to sawmills. Similarly, pulpwood is chipped and exported or used domestically for production of paper or reconstituted wood products. These could, at a certain price point, be diverted towards biofuels or bioelectricity. Plantation harvest residues were until recently burnt on site, but most are now conserved to maintain site nutrients. Some harvestable proportion of this fraction could also be diverted to bioenergy. Thus, the proportion available for bioenergy production will depend on the relative value of these components of biomass compared with other products, the impacts of their removal (e.g. removal of all forestry residues could result in a decline in soil nutrients and thus productivity), government policy settings (tax, incentives etc) and the global oil and carbon prices.

Total amounts (minimum and maximum) of crop, forestry and wood waste for Queensland of current production data were collated from various sources. Where appropriate, proportions of existing biomass fractions were estimated (e.g. C-Molasses as a fraction of total sugar production, stubble as a proportion of grain production, harvest residues as a proportion of wood production).

Data for agricultural biomass were based on the minimum and maximum area and total production data from the years 1983 to 2005 for Queensland. These data stem from the Australian Bureau of Statistics agricultural surveys commodities (see for example, Australian Bureau of Statistics 2004). Crop yields were calculated for each year from production and area statistics; the range of yields over the time period, and the areas of production were used to give minimum and maximum production figures for the study. The scenarios in this study used proportions of the cereals (wheat, barley, oats, sorghum and triticale) diverted to ethanol, and oilseeds (cotton seeds, canola, linseed, safflower, sesame, sunflower and mustard seeds) diverted to biodiesel. Stubble (i.e. straw) from the cereals and oilseed plants (excluding cotton) were estimated by Dunlop *et al.* (2008), and a proportion was diverted to second generation biofuels and bioelectricity.

For forestry biomass, ABARE (2008a, 2008b) provided data on current production from plantations and native forests while the National Plantation Inventory (Parsons *et al.* 2007) provided estimates for future wood production from hardwood and softwood plantations in Queensland up to 2050. Sawmill residues were derived from data provided by ABARE (2008a) indicating that recovery rates of sawn timber for hardwood and softwood sawmills in Queensland were 41% and 44% respectively. These data were used to estimate the amount of sawlogs (and thus sawmill residues) and pulplogs harvested and the amount of harvest residues potentially available for biofuel and bioenergy production.

Most of the wood statistics data were in terms of volume. They were converted to mass using published wood density figures (Ilic *et al.* 2000). Average density was assumed to be 684 kg/m³ for native forest hardwood, 509 kg/m³ for plantation softwood and 641 kg/m³ for plantation hardwood.

Currently, there are 189,000 ha of softwood and 49,000 ha of hardwood plantations (ABARE 2008b). Forecast pulpwood production is estimated to increase from 0.75 million m³/y currently to 0.9 million m³/y by 2030-40 (ABARE 2008b, Parsons *et al.* 2006).

Urban wood waste was estimated using 2007 Waste Management Association of Australia data (WMAA 2007), which summarized "total waste", by weight, for Queensland. This figure was combined with the results of the Wood Waste Landfill Audit (Taylor 2007, Taylor 2008), which indicated the wood waste component of "total waste", by weight.

The landfill audit (Taylor 2007, Taylor 2008) determined the wood waste component of "total waste" to be about 2 % by weight in Queensland. This 2 % was therefore used as the minimum. The national wood waste average was 6 % of total waste (Taylor, unpublished data) by weight. This figure was used as the maximum. Both 2 % and 6 % were taken from the 2007 WMAA "total waste" figure, to determine the current urban wood waste resource, in tonnes.

10.2.4 Future biomass production base – land areas, yields and emissions

A future production base for a given feedstock can be achieved by several means including:

- Expanding, intensifying or shrinking areas of current production (e.g. expanding areas of cropping or conventional plantation

forestry which was assumed in this study) or through yield improvement (which was not assumed here – historical yield ranges were used).

- Purpose-grown energy crops which include short-rotation bioenergy woody plantations; or novel species/production systems e.g. algae for oil for biodiesel.

The analysis was confined to these two options although there are many more land use systems and novel species which can, and should be explored, such as *Pongamia pinnata* for oilseed production or *Agave* for ethanol. These species have not been assessed in this study due to lack of data within the time frame of this study.

The future attainable and potential production scenarios of each feedstock were estimated separately:

In terms of future agriculture production base, there is opportunity to increase the Queensland crop production base using areas currently sown/improved to pastures, which totals about 6 Mha. However, much of this total is relatively low productivity land and therefore not all of it would be suitable for cropping. Thus, it was assumed for the Maximum Potential future scenario that the maximum area could be double the current cropping area (maximum annual area over the years 1983–2005), giving 3.8 Mha for cereals, 0.59 Mha for oilseed crops and 4.39 Mha for stubble production. For the minimum area for the Maximum Potential production base scenario was set as the average of the current agricultural cropping area based on the assumption that cropping would not expand increase due to current and future climatic constraints.

For the future Attainable production scenario, the minimum area was assumed to be the current minimum area (minimum of 1983–2005), and the maximum area was set to 150% of the current maximum area cropped.

The future amount of biomass from plantations depends on the area planted each year, the growth rates of the trees and the time between planting and harvest. Since forest plantations are harvested some 10–30 years after planting, there is a time lag before this material is available. Due to logistical constraints, forest plantations cannot be established instantly and constraint in the maximum establishment rate of forests was also assumed.

Short rotation plantations for dedicated bioenergy production are not currently grown in Queensland, but could be in the future. The design of forestry systems for energy crop production is different to that for conventional forestry products such as pulpwood or sawlogs. The density of planting is higher, and the rotation length is likely to be shorter (3–6 years). A critical difference between agricultural and forestry system is that expansion of forestry leads to a large increase in the stock of carbon in the forest estate — only a small proportion of which is harvested each year. This increased carbon stock in the expanded forest estate was included in the total GHG mitigation effect of short rotation forestry plantations, but not sawlog or pulpwood plantations (see Chapter 7).

Currently there is around 20 Mha of cleared non-cropland in Queensland that could be planted with bioenergy plantations. Thus, the model assumed that the potential area planted with short rotation plantations for bioenergy could range from 1 Mha to 20 Mha. However, to achieve this by 2050 would require a planting rate of 0.5 Mha/y. Thus we assumed a maximum planting rate of 0.1–0.2 Mha/y, resulting in a total area of 8 Mha being planted by 2050.

Due to the large logistical requirements combined with competition with other land-uses, potential impact on water and biodiversity and the distance to existing markets, the attainable area of bioenergy plantations harvestable by 2050 area was considered to be range from 1.5–3.0 Mha corresponding to a planting rate of 50,000 to 100,000 ha/y. Other assumptions included a rotation length of 10 years and a mean annual increment (MAI) of 4 t/ha/y dry weight.

Future quantities of potential and attainable wood waste was calculated by using population data projections (ABS 2007a and b) to calculate current tonnes of “total waste” per person from the 2007 Waste Management Association of Australia data (WMAA 2007). This calculation of tonnes per person was then used to extrapolate, using the same tonnage per person, for predicted maximum and minimum population estimated in 50 years time by the ABS (ABS 2007b). This population-based estimate of “total waste” was then multiplied by the maximum (6%) and minimum (2%), to determine potential maximum and minimum wood waste resource availability.

The attainable wood waste resource was calculated using 3% by weight, estimating a conservative increase in use of wood because of population increase (calculated using the ABS data as above), and increasing efficiency of wood production.

Novel biomass feedstocks may become important in the future. There is a great deal of speculation about the potential for algae to produce biofuel. However there is a lack of data on production in Australian environments; operational methods to scale up production to levels which could provide significant volumes and separation of the oil from the algae remain technical challenges. Campbell *et al.* (2009) assessed the feasibility of algal fuels in Australia and has been used to guide a broad analysis here. This represents a subset of the broader opportunities for algal biodiesel in Queensland – again, driven by where plausible data were available within the time frame of this study.

It has been assumed that algal farms will need to rely on an augmented CO₂ source from power stations because algal growth without additional CO₂ inputs is so low that it would not be economically viable under any plausible oil price for purposes of fuel production (although it still could be productive for high-value outputs such as omega 3 oils, etc, but this was not analysed here). This assumption restricted the locations of potential algae farms to areas where there is sufficient land for the ponds, close to the CO₂ sources and near the ocean for a water source (Campbell *et al.* 2009). Only extremophile algae were assumed viable at large scale (e.g. *Dunaliella* species that can handle high levels of salt water) due to the risk of contamination from other airborne and waterborne algae in open ponds of fresh water.

Three sites in Queensland were considered to have high enough levels of CO₂ production (at least 0.2 Mt/y) in conjunction with suitable land to warrant the production of economically large algae farms; in the SE there were a number of power stations producing on the order of 23 Mt/y CO₂, similarly at Gladstone/Rockhampton (28.9 Mt/y CO₂) and a smaller production area at Townsville (1.3 Mt/y CO₂).

The production system was defined so that the oil was separated from the algae to produce biodiesel. The residual algal biomass was placed in an anaerobic digester, producing methane that was used to produce electricity, which was then fed back into the grid to offset coal/gas fired power station.

Biodiesel production was assumed to be 22.2 kL/ha/y, with approximately 34,000 ha of land available, thus producing some 0.75 GL of biodiesel annually (e.g. three 5,000–6,000 ha algae farms for each of the SE Queensland and Gladstone/Rockhampton areas, with one, probably smaller, farm at Townsville). This was derived from an assumed yield of 20–50 t/ha/y of algae oil, with a similar amount of excess biomass used for methane production (or stock feed), i.e. 40–100 t/ha/y of total biomass.

In addition to coastal areas, algae farms could potentially be co-sited with inland coal seam gas projects, as large quantities of possibly saline water are a by-product of coal seam methane gas production (e.g. Gloucester Gas 2008; Keith *et al.* 2003). Viability and production capacity would be highly dependent upon the amount of non-arable land available nearby; further study would be required before a reliable estimate could be made and these potential areas are not addressed in this study.

10.2.5 Calculate bioenergy equivalents through conversion factors

The amounts of biofuels in current and future production scenarios were estimated by multiplying the following:

- the amounts of feedstock production (see above);
- the proportion of this production assumed to be diverted to biofuel/bioelectricity production;
- an average feedstock-to-fuel conversion efficiency; and
- the ratio of energy content of the biofuel relative to its fossil fuel end-use equivalent (e.g. ULP for ethanol).

The following technologies were considered for converting the biomass feedstocks into biofuel:

- Conventional fermentation for ethanol production from first generation feedstocks (starch, sugar and C-molasses).
- Conventional transesterification for biodiesel production from oilseeds.
- Biodiesel production from algae using centrifusion followed by transesterification and gasification of residues for energy production.
- Ethanol production from lignocellulosic biomass using cellulose hydrolysis and fermentation for second generation feedstocks (stubble, wood waste, forestry and sawmill residues, pulpwood, bioenergy plantations and grasses).
- Synfuel production from lignocellulosic biomass through gasification and gas conditioning and cleaning followed by Fischer Tropsch synthesis and refining of the syncrude liquids for combined production of syndiesel (60% by volume), syngasoline (40% by volume) and bioelectricity.
- Bioelectricity production from lignocellulosic biomass using conventional combustion technology.

Conversion factors were obtained from a review of available published data, from an Australian context where possible. Where Australian specific information was unavailable international averages were used instead. Energy content data were obtained from two sources — constants used in CSIRO's LCA database, and data included in the Department of Climate Change Emission Factors (Department of Climate Change 2008a).

Estimated yields of biofuels and bioelectricity from different feedstocks are provided in Table 10-3.

Table 10-3: Estimated energy and fuel yields for different feedstock technology combinations.

Feedstock	Ethanol L/t	Biodiesel L/t	Synfuel ¹ L/t	Bioelectricity ² MWh/t
First Generation				
Cereals	360 ³	NA	NA	NA
Oilseed	NA	400 ¹¹	NA	NA
Sugarcane				
C-molasses	280 ⁴	NA	NA	NA
Sugar	560 ⁵	NA	NA	NA
Second Generation				
Cereals	335 ⁶	NA	246	1.02
Waste wood	240 ⁷	NA	246	1.35
Algae	NA	495 ¹²	NA	0.27 ¹³
Sugarcane				
Whole plant	465 ⁷	NA	246	0.80
Bagasse	300 ⁷	NA	246	0.80
Forestry				
Sawmill residues	233 ⁸	NA	246	1.35
Harvest residues	233 ⁸	NA	246	1.35
Pulpwood	240 ⁷	NA	246	1.35
Bioenergy plantations	260 ⁹	NA	246	1.35
Grasses	323 ¹⁰	NA	246	1.02

¹ Kreutz, T.G., Larson, E.D., Liu, G., Williams, R.H. (2008)

² Assumed 30% energy conversion efficiency with energy contents from DCC (2008a)

³ International Energy Agency (2004); Rutovitz, J. and Passey, R. (2004)

⁴ Rutovitz, J. and Passey, R. (2004)

⁵ Australian Cane Growers Council (2005)

⁶ International Energy Agency (2004); Warden, A. and Haritos, V. (2008)

⁷ O'Connell et al. (2007a)

⁸ Sims, R., Taylor, M., Saddler, J. and Mabee, W. (2008); O'Connell et al. (2007a)

⁹ Foran, B. and Mardon, C. (1999); Bartle, J. (2006)

¹⁰ International Energy Agency (2004); O'Connell et al. (2007a)

¹¹ Smeets, E.M.W., M. Junginger and Faaij A.P.C. (2005)

¹² Campbell, P.K., Beer, T., Batten, D. (2009)

¹³ Produced as a coproduct of the algae-biodiesel process (Campbell, P.K., Beer, T., Batten, D., 2009)

10.2.6 Estimate the production emissions

Total production emissions, based on published Life Cycle Assessments (LCA), were assembled for each biomass type, where possible specific to Queensland production systems. This task was complex because of the range of assumptions, system boundaries and allocation methods used in various studies which were reviewed.

Production emissions for cereals and oilseed were estimated to range from 150-250 kg CO₂-e/t (Farine et al. 2008), while those for dry whole sugarcane ranged from 30-60 kg CO₂-e/t (O'Connell et al. 2008). A life cycle inventory of wood production from plantations and native forests in Australia provided estimates of greenhouse gas emissions from management, harvest and haulage of softwood including all upstream emissions from production of fuel, energy and materials and non-CO₂ emissions from fertiliser use and burning (47 kg CO₂-e/t; May et al. In press). Emissions from hardwood and bioenergy plantations were assumed to be greater (60 kg CO₂-e/t) as a result of the increased production intensity (e.g. shorter rotation length and increased fertiliser requirements). Emissions from production of algae for biodiesel production were estimated to be -0.4 g/L from a recent review of life cycle studies of greenhouse gas sequestration by algae (Campbell et al. 2009). The negative emissions for this process are due to the use of methane produced from waste biomass for electricity production. Emissions from production of wood waste and sawmill residues were assumed to be negligible. For each estimate the range (based on the minima and maxima) was also provided based on estimates from the respective studies.

Total production emissions were allocated to different fractions of each potential feedstock. This step can be done in many different ways, and is often a contestable step in LCA. For example, in this report, 100% of total production emissions of cereals were allocated to the grain and 0% to the stubble, because the cereal is grown primarily for grain. There are valid arguments that this step could be done in at least 2 other ways: (i) via relative mass proportions or (ii) via economic allocation i.e. according to their relative prices. In the case of purpose-grown feedstock such as bioenergy plantations, 100% of the emissions were allocated to the plantation. For biomass from sawlog or pulpwood plantations, production emissions were allocated to different products on a relative mass basis.

10.2.7 Estimate transport and conversion emissions

As with emission from production of feedstocks, there have been many studies of the emissions associated with the conversion processes. As well as the lack of direct comparability in studies due to assumptions and system boundaries, the emission numbers are often expressed in different compound units which are difficult to disaggregate into the simpler units used in this study (kg CO₂-e/L biofuel). In addition, many emerging technologies are either commercial-in-confidence, or very speculative in their estimates of yields and emissions. This makes estimation of the conversion emissions from review difficult, and less reliable than for the production emissions, where at least the production systems are well understood and documented.

Emissions from transport of sugarcane were based on average figures for transport of wet cane by light rail in Queensland (0.77 kg CO₂-e/t wet or 1.6 kg CO₂-e/t dry; CSIRO *unpubl. data*). These were allocated to the final product (sugar) on the basis of a 25% conversion rate to give 6.4 kg CO₂-e/t with no production or transport emissions allocated to the coproducts C-molasses or bagasse. Emissions associated with transport of pulplogs were based on data from the forestry LCI (16 kg CO₂-e/t dry wood based on a 50 km lead distance and 42 t/load; May *et al.* In press). No data were available for emissions associated with transport of other biomass types. Thus, transport emissions for forest harvest residues, biomass from bioenergy plantations and cereal stubble were assumed to be the same as for wood, while those from transport of grain and oilseed were assumed to be half those of pulpwood because of the lower moisture content (~10% compared with ~50% for wood). Emissions from transport of algae, wood waste and sawmill residues were assumed to be negligible because it was assumed that any bioenergy or biofuel facilities would be located either on or close to the production site.

Emissions from conversion of first generation feedstocks to ethanol were derived from unpublished CSIRO data using the SimaPro Life Cycle Analysis model (PRé Consultants 2007; CSIRO *unpubl. Data*, 0.5 kg/L, 0.6 kg/L and 0.3 kg/L ethanol produced for grains, C-molasses and sugar respectively). Energy for conversion of second generation feedstocks (stubble, wood waste and forest biomass) to ethanol was assumed to come from waste products (primarily lignin) from the process and thus require no fossil fuel input (e.g. Lindfelt and Westermarck 2008). Thus, emissions for production of ethanol from these feedstocks were assumed to be zero. Emissions from conversion of algae to biodiesel were included in the overall emissions from algal production.

Emissions for conversion of biomass to synfuel were assumed to be negligible because the process uses energy from the process itself and is a net exporter of electrical energy. These assumptions are based on the calculations for the Fischer-Tropsch model of a large biomass to liquids and electricity plant (1 Mt/y of biomass) which recycles unconverted syngas and vents CO₂ to the atmosphere (Kreutz *et al.* 2008).

Emissions from bioelectricity production (in terms of the LHV energy content of the biomass feedstock) were assumed to be 1.3 kg CO₂-e/GJ for wood waste, 1.5 kg CO₂-e/GJ for bagasse and 1.8 kg CO₂-e/GJ for other solid biomass based on figures from DCC (2008a). Using an assumed conversion efficiency of 30% these are equivalent to 15.6 kg CO₂-e/MWh electricity produced from wood waste, 18.0 kg CO₂-e/MWh electricity produced from bagasse and 21.6 kg CO₂-e/MWh electricity produced from other solid biomass.

10.2.8 Estimate emissions from current energy and fuel production for calculation of offsets

Emissions from current production of electricity, gasoline and diesel were based on estimates from DCC (2008a). The figure for full fuel cycle emissions for electricity production from black coal in Queensland for end users was 93 kg CO₂-e/GJ feedstock. Using a conversion efficiency of 35% for electricity from black coal (DCC 2008b) gave a total of 940 kg CO₂-e/MWh. Figures for production of liquid fuels were 72.4 kg CO₂-e/GJ (2.8 kg CO₂-e/L) and 74.8 kg CO₂-e/GJ (2.9 kg CO₂-e/L) for gasoline and diesel respectively (DCC 2008a). Since the assumed energy contents of ethanol (24.5 MJ/L) and biodiesel (34.0 MJ/L) were less than the respective figures for gasoline (32.5 MJ/L) and diesel (38.4 MJ/L) the emissions from the fossil fuels were expressed in terms of energy equivalents.

10.3 Scenarios for production of first generation biofuels, second generation biofuels and bioelectricity

Simple scenarios were defined and applied to each category of conversion technologies, grouped into first generation biofuels, second generation biofuels and bioelectricity. The scenario settings were set independently for each feedstock. This was necessary

because the nature of each production system is very different in terms of emission profiles, and the potential trajectory for expansion into the future.

Broad scenarios for each technology category were:

Current or Business as Usual (BAU): Net Carbon Storage (t CO₂-e) from 2010 to 2050. Feedstock production and diversion to biofuels for 2010 were based on real data. Trajectory estimates to 2050 for production and diversions to biofuels varied for each feedstock.

Maximum Potential: The upper limits level that is biophysically possible. Note: in this chapter, we have moderated this definition by applying some constraints of changing from current land and product uses, as well as applying reasonable rates and magnitudes of upscaling (e.g. a maximum establishment rate of 200,000 ha/yr was used for forestry).

Attainable: The level attainable given concerted efforts to implement the technology/management changes taking into account uncertainty of estimates and the biophysical adjustment that may be needed to make a new system work.

The different variables (area planted, yield, total production, and production emissions) were calculated separately for each biomass source and all had minimum and maximum values to take account of uncertainty and variation. Therefore, for each scenario, an aggregate minimum and maximum set of values was obtained, and summed across the relevant feedstocks. Some of the variables that were set for each feedstock are shown in Table 10-4. The data for Business as Usual were constrained by the current actual production base for the starting year (2010) and an estimated trajectory for the proportion of this production diverted to biofuel production by 2050.

Table 10-4: An example of the scenario settings for each feedstock.

Feedstock	Cereals Stubble		Product	Syndiesel	
	Max Utilisation t/yr	Current utilisation %	Final utilisation %	Time to Start years	Time to Full Utilisation Years
Business as Usual (min)	1,638,000	0%	5%	5	10
Business as Usual (max)	6,798,300	0%	5%	5	10
Potential (min)	2,535,000	0%	100%	5	20
Potential (max)	13,596,600	0%	100%	5	20
Attainable (min)	1,638,000	0%	50%	5	20
Attainable (max)	10,197,450	0%	50%	5	20

The full range of settings for each feedstock in each scenario is provided in Table 10-9 for first generation biofuels and Table 10-10 for second generation biofuels and bioelectricity.

10.4 Results and discussion

The annual and cumulative CO₂-e achieved with various settings of each feedstock were summed for first and second generation feedstocks as listed in Table 10-9, Table 10-10 and Table 10-11 plotted as graphs Figure 10-1, Figure 10-2, and Figure 10-3. Estimated total fuel and energy production from first and second generation biofuels under the BAU, Max Potential and Attainable scenarios are shown in Table 10-5, Table 10-6 and Table 10-7. In addition to the total carbon mitigation from the different scenarios for each technology, the proportionate contribution from each individual feedstock over time is shown based on the average of the Attainable scenario.

10.4.1 First generation biofuels

Estimates for annual ethanol and biodiesel production from first generation biofuels by 2050 under the three scenarios (Business as Usual, Max Potential and Attainable) are shown in Table 10-5. Production and utilisation parameters for the various feedstocks (cereal grain, oilseed, sugar and C-molasses) under the three scenarios are shown in Table 10-9. Under the Business as Usual scenario, only a small portion of current feedstock production was assumed to be diverted (e.g. 10% for cereal and oilseed grain, up to 75% for C-molasses and 0% for sugar). Under the Maximum Potential scenario, an expanded land base for cereal and oilseed production was assumed with all of this as well as 100% sugar and C-molasses diverted to biofuel production. Under the Attainable scenario, an intermediate expansion of cereal and oilseed crops was assumed with 20% of cereal, oilseed and sugar and 100% of C-molasses diverted to biofuel production.

Total production of first generation biofuels was estimated to reach 100-300 ML/y by 2050 under the Business as Usual scenario, 2,600-6,200 ML/y under the Max Potential scenario and 700-1,400 ML/y for the Attainable scenario. The energy contents of ethanol (23.4 MJ/L) and biodiesel (33.2 MJ/L) are lower than those for unleaded petrol (34.2 MJ/L) and low sulphur diesel (38.6 MJ/L, DCC 2008a, EPA 2002). Thus, these amounts are equivalent (in energy terms) to 100-200 ML/y gasoline under the Business as Usual scenario, 1,700-4,000 ML/y gasoline and 100-300 ML/y diesel under the Max Potential scenario and 500-900 ML/y gasoline and 0-100 ML/y diesel under the Attainable scenario.

Table 10-5: Estimated ethanol (from cereals and sugar cane) and biodiesel production (from oilseeds) under the Business as Usual (BAU), Max Potential and Attainable scenarios by 2050. Note: There are important sustainability considerations not taken into account in this scenario.

Feedstock	BAU		Max Potential		Attainable	
	Min ML/y	Max ML/y	Min ML/y	Max ML/y	Min ML/y	Max ML/y
Cereals	0	100	500	2,600	100	400
Oilseed	0	0	100	400	0	100
Sugar						
C-molasses	100	200	200	300	200	300
Sugar	0	0	1,800	2,900	400	600
Total						
Ethanol	100	300	2,500	5,800	700	1,300
Biodiesel	0	0	100	400	0	100
Total	100	300	2,600	6,200	700	1,400

Results for the mitigation of emissions through substitution of ethanol and biodiesel for gasoline and diesel are shown in Figure 10-1. For the Max Potential scenario, emission mitigation from using all sugar, grains and oilseeds was estimated to reach 3.4-9.3 Mt CO₂-e/y by 2050 (for a total mitigation effect of 110 - 290 Mt CO₂-e over the 40 years). The upper limit was attained assuming the Max Potential increase in production areas and minimum emissions from production and conversion of the biomass to biofuel.

The Business as Usual scenario mitigation of 0.3-0.5 Mt CO₂-e/y by 2050 (10-20 Mt CO₂-e over the 40 years) and the Attainable scenario mitigation of 0.9-2.0 Mt CO₂-e/y by 2050 (30 - 60 Mt CO₂-e over the 40 years) showed narrower ranges, and lower overall mitigation (Figure 10-1). This was driven by the probable low diversions of sugar, starch and oilseeds into biofuels because of their value as human food and animal feed. Despite this low diversion, ethanol from sugar comprised around half the average Attainable mitigation of emissions as a result of its relatively high yield (560 L/t) with ethanol from C-molasses and grain contributing 27% and 16% respectively to the total mitigation of emissions from first generation feedstocks (Figure 10-1c).

The uncertainty ranges shown are as important as the absolute values and show the large variation (differences between crops, regional environmental factors and management) as well as scientific uncertainty (production into the future, proportion of diversion to biofuels, production and conversion emissions). All of these factors require further investigation to obtain more reliable estimates.

10.4.2 Second generation biofuels

Production and utilisation parameters for second generation feedstocks under the three scenarios are shown in Table 10-10. Under the Business as Usual scenario, feedstock production was assumed to come from the existing land base with competition for feedstock from other industries limiting its availability for biofuel production. The Max Potential scenario assumed an expanded land base for agricultural and forestry production as well as new feedstocks from short rotation forestry in grazing lands and algae farms (near 3 large power stations) for production of biofuels, with all other production of lignocellulosic material (excluding sawn timber) diverted to biofuel production. Under the Attainable scenario, an intermediate expansion of the production land was assumed with 50% of stubble, 80% of wood waste, forestry and sawmill residues, 30% of pulpwood, and 100% of algae, bioenergy plantation biomass available for biofuel production.

Estimates for annual ethanol, biodiesel, syndiesel and syngasoline production from second generation feedstocks (cereal stubble, wood waste, algae, forestry and sawmill residues, bioenergy plantations) under the three scenarios by 2050 are shown in Table 10-6a and Table 10-6b.

Total production of ethanol and biodiesel ranged from 600-1,000 ML/y under the Business as Usual scenario, 4,300-15,100 ML/y under the Max Potential scenario and 1,600-6,100 ML/y for the Attainable scenario (Table 10-6a). These amounts are equivalent (in energy terms) to 400-700 ML/y gasoline under the BAU scenario, 2,700-9,600 ML/y gasoline and 300-900 ML/y diesel under the Max Potential scenario and 1,000-3,800 ML/y gasoline and 100-400 ML/y diesel under the Attainable scenario. In addition, a net 0.2-0.6 TWh/y electricity was estimated to be produced as a result of biodiesel production from algae under the Maximum Potential scenarios and 0.1-0.3 TWh electricity under the Attainable scenario.

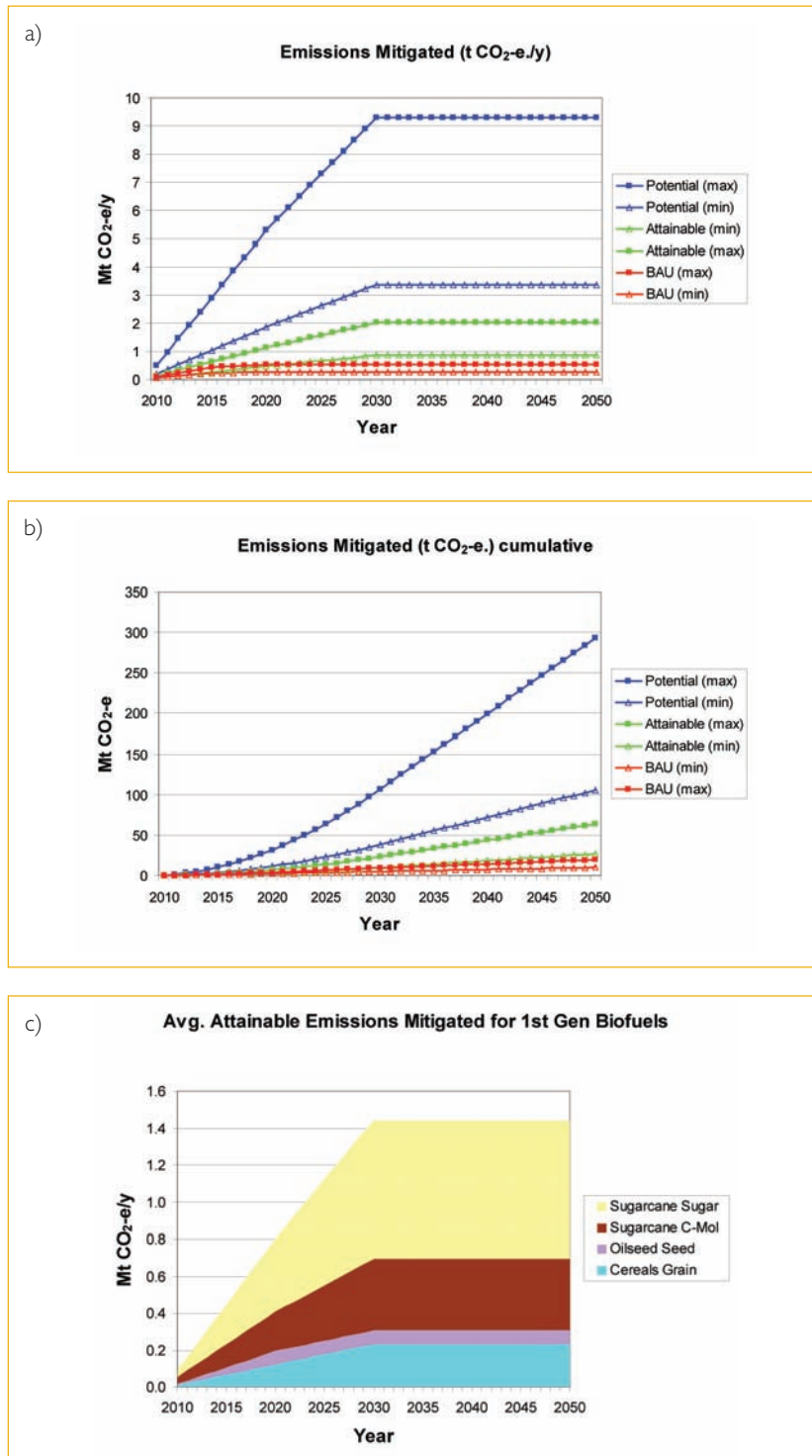


Figure 10-1: Carbon mitigation for first generation biofuels (ethanol and biodiesel from grain, oilseed, sugar and C-molasses) shown as (a) annual mitigation (b) cumulative mitigation (c) average annual contributions by feedstock for Attainable mitigation scenario. Note: There are important sustainability considerations not accounted for in this scenario.

Alternatively, estimated combined production of syndiesel and syngasoline from the synfuel process was 500-800 ML/y, 3,900-13,100 ML/y and 1,500-5,600 ML/y for the Business as Usual, Max Potential and Attainable scenarios respectively (Table 10-6b). Biodiesel from algae added an extra 300-1,000 ML/y under the Max Potential scenario and 100-500 ML/y under the Attainable scenario.

Table 10-6: a) Estimated production of biodiesel (from algae) and ethanol (other feedstocks) from second generation feedstocks and b) estimated production of synfuel (40% syngasoline and 60% syndiesel by volume) from second generation feedstocks under the Business as Usual (BAU), Max Potential and Attainable scenarios by 2050.

a) Feedstock	BAU		Max Potential		Attainable	
	Min	Max	Min	Max	Min	Max
	ML/y	ML/y	ML/y	ML/y	ML/y	ML/y
Stubble	0	100	800	4,600	300	1,700
Waste wood	0	0	100	100	0	100
Algae	0	0	300	1,000	100	500
Sugarcane Bagasse	600	900	1,200	1,900	600	900
Forestry						
Sawmill residues	0	0	100	200	100	200
Harvest residues	0	0	100	200	0	100
Pulpwood	0	0	100	100	100	300
Bioenergy plantations	0	0	1,600	7,000	400	2,300
Total						
Ethanol	600	1,000	4,000	14,100	1,500	5,600
Biodiesel	0	0	300	1,000	100	500
Total	600	1,000	4,300	15,100	1,600	6,100

b) Feedstock	BAU		Max Potential		Attainable	
	Min	Max	Min	Max	Min	Max
	ML/y	ML/y	ML/y	ML/y	ML/y	ML/y
Stubble	0	100	600	3,300	200	1,300
Waste wood	0	0	100	100	0	100
Algae ¹	0	0	300	1,000	100	500
Sugarcane Bagasse	500	700	1,000	1,600	500	800
Forestry						
Sawmill residues	0	0	200	200	100	200
Harvest residues	0	0	100	200	0	200
Pulpwood	0	0	100	100	200	300
Bioenergy plantations	0	0	1,500	6,600	400	2,200
Total						
Syngasoline	200	300	1,400	4,800	600	2,000
Syndiesel	300	500	2,200	7,300	800	3,100
Biodiesel I	0	0	300	1,000	100	500
Total	500	800	3,900	13,100	1,500	5,600

¹ Algae assumed to be converted to biodiesel rather than syndiesel.

In addition, bioelectricity production through the synfuel and algae-biodiesel process was estimated to provide an additional 0.6-0.9 TWh/y bioelectricity under the BAU scenario, 3.9-14.0 TWh/y bioelectricity under Max Potential scenario and 1.5-5.7 TWh/y electricity under the Attainable scenario. Thus, although the total volume of syndiesel and syngasoline produced was less than that for ethanol, the higher energy content of the fuels, combined with the additional bioelectricity generated, resulted in the total energy yield for the synfuel process being 40%-50% greater than that for the ethanol production process for most feedstocks.

Emission mitigation as a result of substituting biofuels (syngasoline and syndiesel) and bioelectricity from the Fischer-Tropsch process and biodiesel from algae for fossil fuels and electricity was greater (15-25%) than that possible with ethanol production because of the lower energy efficiency of the latter. Results for the mitigation of emissions under the different scenarios are shown in Figure 10-2. Maximum potential mitigation from synfuel and biodiesel production was estimated to reach 14-47 Mt CO₂-e/y by 2050 (for a total of 400-1,100 Mt CO₂-e over the 40 years). The upper limit was attained assuming the maximum potential increase in production areas and minimum emissions from production and conversion of the biomass to biofuel.

The Business as Usual scenario (reaching 2-3 Mt CO₂-e/y by 2050 or 50-90 Mt CO₂-e over the 40 years) and the Attainable scenario (reaching 5-18 Mt CO₂-e/y by 2050 or 130-420 Mt CO₂-e over the 40 years) showed narrower ranges, and lower overall mitigation (Figure 10-2 and Table 10-10) than the Max Potential scenario. The largest contributions to average 'attainable' emissions were bioenergy plantations (37%), bagasse (19%) and cereal stubble (21%).

Grasses were not included in the scenarios due to insufficient and unreliable data. However, given the large potential, for biomass production from pastures across Queensland, further research into this area is warranted.

The uncertainty ranges shown are as important as the absolute values and show the large variation (differences between crops, regional environmental factors and management) as well as scientific uncertainty (production into the future, proportion of diversion to biofuels, production and conversion emissions). All of these factors require further investigation to obtain more reliable estimates. Conservative estimates for the 'new and novel' sources of bioenergy, short rotation plantations and algae were used in the Attainable scenario. The contribution of these feedstock sources in the Max Potential scenario was much greater than that indicated in the Attainable scenario in Figure 10-2c.

The interactions between land uses were not modelled. Upper limit constraints were placed upon the amount of land that could be put to each type of feedstock production, but dynamic modelling is required to model any real land use changes out to 2050 with improved reliability.

10.4.3 Bioelectricity from second generation feedstocks

Estimated diversion of feedstock for bioelectricity production under the three scenarios was assumed to be the same as that for second generation biofuels (i.e. Table 10-7).

Estimated production of bioelectricity from second generation feedstocks by 2050 as an alternative to using them for biofuel under the three scenarios is given in Table 10-7. Total annual electricity production ranged from 1.7-2.9 TWh under the Business as Usual scenario, 15.9-60.0 TWh under the Max Potential scenario and 6.2-24.0 TWh under the Attainable scenario. The upper limit for the Max Potential scenario represents just under 50% of the forecast total electricity generation requirement for the whole of Queensland by 2030 (125 TWh, ABARE 2007b).

Results for the estimated reduction in emissions as a result of substituting bioelectricity for current coal generated electricity in Queensland (which provides ~90% of the total current electricity requirements) are given in Figure 10-3. For the Max Potential scenario, emission mitigation was estimated to reach 15-58 Mt CO₂-e/y by 2050 (for a total mitigation of 500-1,400 Mt CO₂-e over 40 years). This was almost the same as the mitigation effect from synfuel production due to the similar energy efficiencies of the two processes. The upper limit was attained assuming the maximum potential increase in production areas and minimum emissions from production and conversion of the biomass to bioelectricity.

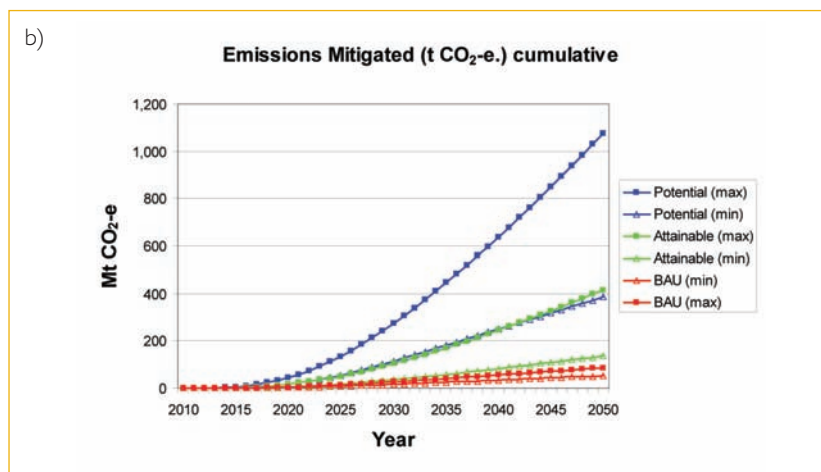
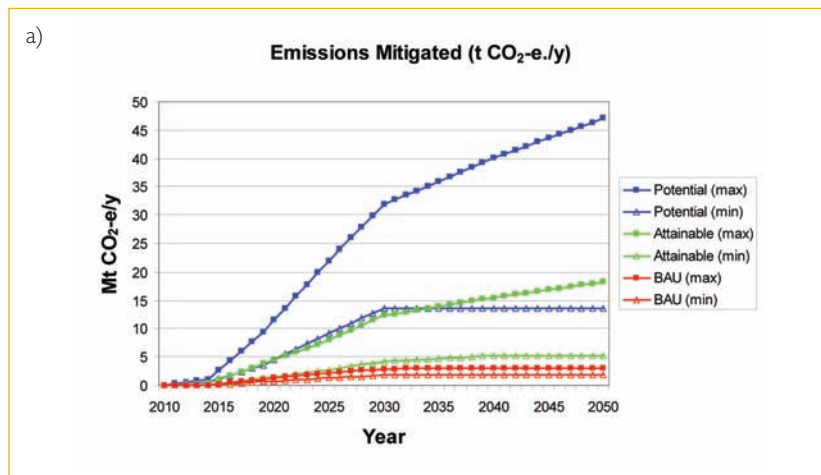
Table 10-7: Estimated production of bioelectricity from second generation feedstocks by 2050 under the Business as Usual (BAU), Max Potential and Attainable scenarios.

Feedstock	BAU		Max Potential		Attainable	
	Min TWh/y	Max TWh/y	Min TWh/y	Max TWh/y	Min TWh/y	Max TWh/y
Stubble	0.1	0.3	2.6	13.8	0.8	5.2
Waste wood	0.0	0.0	0.3	0.8	0.2	0.3
Algae ¹	0.0	0.0	0.2	0.6	0.1	0.3
Sugarcane Bagasse	1.6	2.4	3.2	5.2	1.6	2.5
Forestry						
Sawmill residues	0.1	0.1	0.8	1.2	0.5	1.0
Harvest residues	0.0	0.1	0.3	1.3	0.2	0.9
Pulpwood	0.0	0.0	0.4	0.8	0.8	1.7
Bioenergy plantations	0.0	0.0	8.1	36.5	2.0	12.2
Total	1.7	2.9	15.9	60.0	6.2	24.0

¹ Bioelectricity produced as a coproduct of algae to biodiesel process.

The Business as Usual scenario (80–130 Mt CO₂-e over 40 years) and the Attainable scenario (200–590 Mt CO₂-e over 40 years) produced narrower ranges, and lower overall mitigation (Figure 10-3 and Table 10-11). As with the biofuel scenario, the largest contributions to average Attainable emissions were from short rotation plantations, bagasse and cereal stubble.

As with second generation biofuel production, the uncertainty ranges for bioelectricity production are very large. Similarly interactions between different landuses were not modelled. All of these factors require further investigation to obtain more reliable estimates.



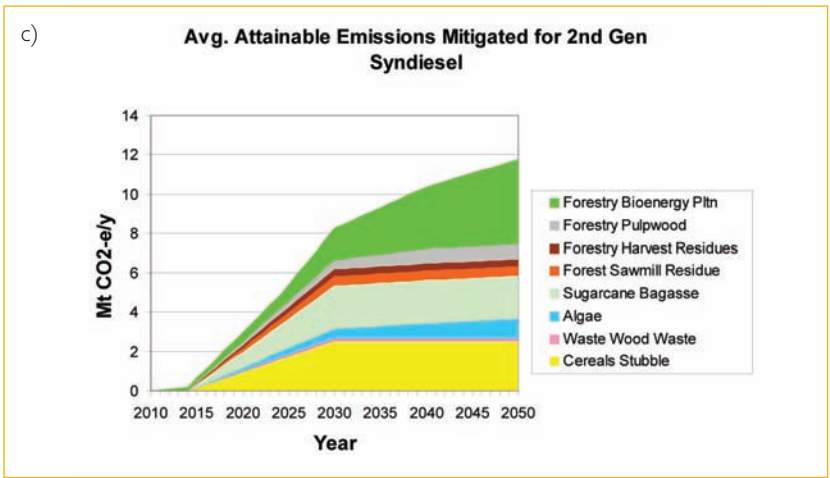
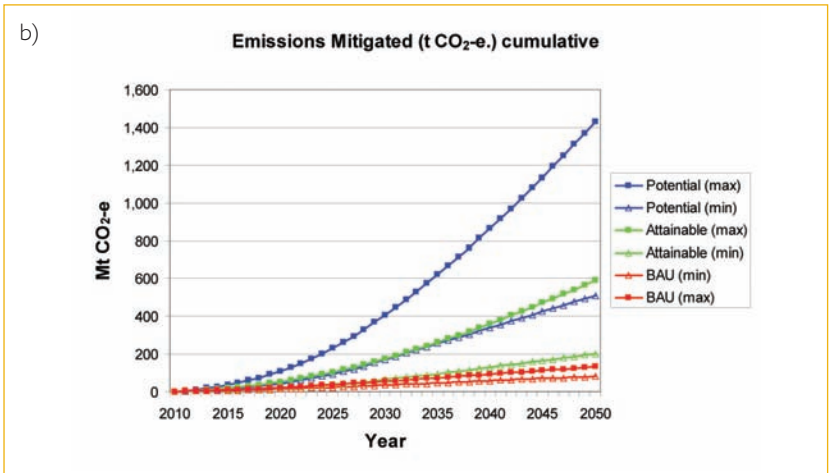
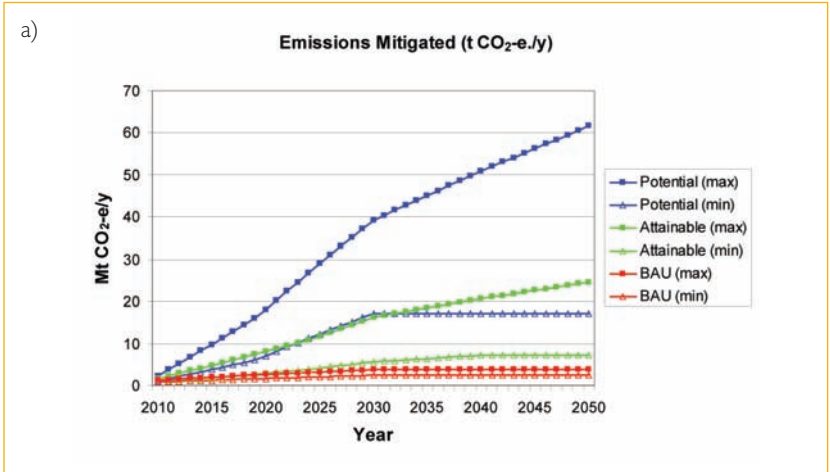


Figure 10-2: Carbon mitigation for second generation biofuels (syndiesel, syngasoline production) shown as (a) annual mitigation (b) cumulative mitigation (c) average annual contributions by feedstock for Attainable mitigation scenario.



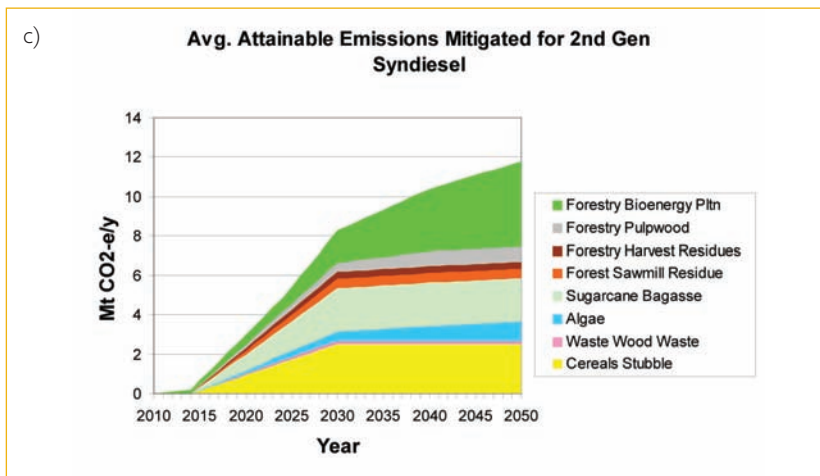


Figure 10-3: Carbon mitigation for bioelectricity shown as (a) annual mitigation (b) cumulative mitigation (c) average annual contributions by feedstock for Attainable mitigation scenario.

10.5 Defining uncertainty

The ranges of variation in each of the potential options have been provided in the graphs (Figure 10-1, Figure 10-2, and Figure 10-3). The uncertainty ranges were chosen by addition of variation at each step of the calculations, with some subjective assumptions about future land use changes, and therefore do not represent probabilistic limits. The main sources of variation include regional, seasonal and management differences in:

- production areas — particularly in the future scenarios which include potential expansion or contraction of some land uses;
- yields;
- emissions due to different environment x management combinations;
- conversion efficiencies; and
- amounts of biomass diverted to biofuel/energy production.

The sources of uncertainty include:

- future changes in land use and production of feedstocks;
- emissions from production of the feedstock (especially those related to N₂O and methane);
- allocation of the proportionate emissions to various components of any feedstock (e.g. allocating all of the production emissions of cereal to the grain component rather than the stubble component); and
- effects of removal of crop and forest residues on the soil carbon stock (not modelled here).

The prospects and parameters for new production systems — short rotation forestry and algae — are considerably more uncertain than either current production systems, or their expansion. Likewise, second generation conversion technologies are considerably more uncertain than first generation technologies. Thus the estimates for those scenarios for first generation biofuels or bioelectricity based on current production systems are relatively robust in comparison to those based on second generation technologies and new future production systems for feedstocks.

In order to reduce the uncertainty of estimates, more robust estimates of emissions especially from N₂O and methane, and LCAs for each pathway based on a comparable set of assumptions and system boundaries would be useful. Although the data for production, transport and conversion emissions were sourced from a range of LCA studies, the disparities between the different studies have added high levels of uncertainty and variation. LCAs which included the consequences of removing the biomass would probably reduce the mitigation benefits. In addition, in this work we have used very simplistic assumptions about future production base. In order to provide more robust estimates, a study with spatial disaggregation of estimates, and spatial analysis of projected land use change would reduce the uncertainty and error.

10.6 Risk and barriers to implementation

Research and development into the areas of feedstock production and conversion technologies is underway — although at very

small levels of R&D investment in Australia compared to overseas efforts. Thus one of the barriers and risks is that many of the biofuel and bioelectricity options outlined in this chapter will have no pathway to realisation.

It is widely accepted in Australia that the future of any significant scale-up in bioenergy production must be in second generation technologies, due to the issues that have arisen internationally with large-scale diversion of grain, canola and palm oil to biofuels (O'Connell *et al.* 2007a, O'Connell *et al.* 2007b). There is a view that second generation biofuels will negate the risks to food security by using lower productivity land for production of lignocellulosic and algal feedstocks in the future. This is an attractive option, but suffers the risk that low productivity land will lead to poor yields and make transport distances uneconomic. Therefore there is a residual risk that if the economic conditions were conducive, higher productivity land could be used for production of energy crops and thus compete for land and water that would otherwise be used for food production. There are also biosecurity risks associated with the introduction of high biomass production crops which have similar functional traits to invasive weeds.

The current small scale first generation industry in Australia will help to pave the way for any future second generation industry, but there is a risk that the current industry will not survive the uncertainty of the economic conditions (highly volatile feedstock, oil and energy prices) and the policy environment (volatile and inconsistent state and federal policies and legislation pertaining to mandates, tax treatments etc.; see Batten and O'Connell 2007a).

There is little opportunity in Australia for a large scale-up of first generation biofuels - indeed the risk is more the complete collapse of this industry. The current small size of the industry provides the opportunity for further industry scale up to occur along more sustainable pathways. The lack of a formal system for demonstrating sustainability credentials is a barrier to consumer confidence, industry development and, in the future, access to international markets. This barrier is one that can be addressed — and hopefully will be in the near future as many sustainability frameworks are currently under development internationally (see Cramer 2007, Un-E 2007, EPFL 2008, UNCTAD 2008, O'Connell *et al.* in prep.).

10.7 Compliance and auditing

There are many issues complicating the measurement of emissions and mitigation potential from agriculture and forestry, and these also affect these estimates in the production phase of bioenergy. Through the remainder of the value chain (transport, conversion to biofuel and bioelectricity, distribution and consumption) the technology to measure the GHG emissions and other impacts are considerably more tractable.

It is feasible to establish a third party monitoring and auditing system – this could be part of a sustainability framework for certification as discussed above. There are many international activities working towards this end, and any system developed in Australia should be compatible and mutually recognised. It would need to build on existing systems for forestry (e.g. Forest Stewardship Council which is broader than carbon accounting, National Carbon Accounting System for carbon accounting only) and agriculture (no recognised and implemented system).

10.8 Other benefits and consequences

As has been illustrated by the examples provided here, biofuels and bioelectricity cover a wide spectrum of pathways to implementation and each would have very different consequences, risks and benefits depending on the pathway, the scale of operation and the location.

For example, establishment of short rotation forestry plantations in low productivity areas was shown in this analysis to have large carbon storage benefits, and could also have added biodiversity benefits. The potential carbon benefits obtained by a working short rotation forest, as compared to a forest with long rotations (or indeed no harvest), deserve further discussion and this is handled in section 10.12. In high rainfall areas, there may be an unintended consequence of interception of surface water and diminishing streamflow. Removal of agricultural and forest residues has mitigation benefits, but the trade-off with removal of carbon from the ecosystem and impact on soil health have yet to be quantified. Introduction of new species may provide immense mitigation benefits – but some of them may have bio-security risks. Any new industry in regional areas may have potential benefits to rural and regional economies.

The issues that are most challenging, however, are not the direct impacts but rather the indirect impacts. The interactions between these are described here, summarised from O'Connell *et al.* (in prep.). In Australia, the biofuels industry is currently operating at a very small scale. It produces <1% of Australia's fuel, and has practically no impact on existing food chains because it is largely based on coproducts from existing value chains (e.g. waste vegetable oil and tallow for biodiesel; C-Molasses or waste flour starch for ethanol). The supply of these coproducts is, however, very small, placing a very limited ceiling on the amount of biofuel that can be produced from these feedstocks. Further scaling up of industry based on first generation technologies without an expansion in the

production base will necessarily start to divert grain or sugar away from human food and animal feed value chains.

Internationally, there has been very dramatic scale-up of first generation technologies, leading to an increased demand on sugar and corn (for ethanol), and rapeseed and palm oil (for biodiesel) supply chains. Economic theory predicts that when demand outstrips supply, prices hit short term highs, and the rapid increase in biofuels demand was one of the causes (although not the only one) of food price highs through 2007 and 2008. In the medium term, however, economics will dictate that supply will expand to fulfil the new demand regime with the long term price stabilising slightly above the cost of production.

These mechanisms do not hold, however, when there are constraints on resources, as there are on arable land and water in Australia – expansion of production will have limits due to many competing uses of the land (human food, animal feed, fibre, energy, water yield, biodiversity and C sequestration). It is true, however, that this expansion of supply may be achievable in many areas of the world where arable land is currently idle, sometimes as a result of payments (e.g. Hoogwijk *et al.* 2009).

More difficult issues arise when the consequences of expanding the supply leads to other land uses becoming displaced – often in locations distant to the actual industry driving the demand. One example of this was expansion of palm oil production in Asia, which directly led to rainforest clearing for more plantations. The public outcry led to the formation of the Roundtable on Sustainable Palm Oil which produced guidelines for certification of sustainable produce. But, despite good intentions, the outcome is still that the existing palm oil plantations produce 'sustainably produced palm oil' for those new markets which require it, but the market which was previously serviced by those plantations still demands, and is less discerning of, the sustainability credentials. The outcome of rainforest clearing is therefore not tractably addressed if only one market segment (biodiesel) demands sustainability certification.

Second generation technologies will open up new potential supplies of 'wastes' or 'coproduct' feedstocks. The magnitude of these supplies and the implications of using them are under research currently (e.g. Taylor 2008, Dunlop *et al.* 2008). There is evidence from other regions of the world that producing second generation feedstocks can be cost-effective with low-input production systems, on low productivity land. If this proved to be the case for Australia (again, it is the subject of active research), then there would indeed be a great deal of land in Australia that could potentially be used for energy production. It may also, however, in certain economic circumstances and geographic areas, compete indirectly for the land, water and labour currently used for food, sawlog or fibre production or environmental services in higher productivity landscapes and could adversely impact on biodiversity and cultural values.

The potential substitution of land use in the face of multiple competing and rapidly changing priorities (e.g. food production, water yield, energy production, carbon sequestration and biodiversity conservation) raises complex issues and tradeoffs (see example in 10.12). Unless these issues are addressed, it may be difficult for the government, regulatory authorities and consumers to gain full confidence in the sustainability credentials of biofuels (O'Connell *et al.* in prep).

10.9 Comparison of mitigation from bioenergy plantings vs. carbon plantings over time

Newly established or regenerating forests that are not harvested mitigate GHG emissions by increasing the carbon stored in biomass, soil carbon and litter – i.e. creating a carbon sink. In comparison, forests that are harvested periodically for bioenergy production mitigate GHG emissions by these same mechanisms (albeit at lower levels due to the harvesting of some proportion of the estate each year), in addition to reducing GHG emissions by offsetting the fossil fuel-based GHG emissions.

The pattern of emission mitigation from short rotation bioenergy plantations over time depends on the rate of planting, the growth rate and the rotation length (time between planting and harvest). A simple model was developed to compare the mitigation potential over time of short rotation plantings (both in terms of carbon sequestered in standing biomass and replacement of fossil fuel based energy), and new forests which are left unharvested as long term carbon sinks.

Stand growth rate for the model was based on the general growth curve developed for the National Carbon Accounting System (NCAS) and used by Lawson *et al.* (2008) to estimate potential carbon sequestration by forestry in Australia

$$M_a = M_{\max} * e^{(-2 * a_g + 1.25) / a}$$

Where M_a is the standing biomass above ground at Age a , M_{\max} is the maximum above ground biomass for a site, a_g is the age of maximum growth rate. Biomass increment is calculated by subtracting M_a from M_{a+1} .

For this scenario M_{\max} was assumed to be 90 t/ha (based on average productivity on a low rainfall site in Queensland) and a_g was assumed to be 3 years (typical for a short rotation plantation). The resultant growth curves for current annual increment (the amount of additional biomass produced each year), mean annual increment (the average rate of biomass growth since planting) and total biomass production are shown in Figure 10-4.

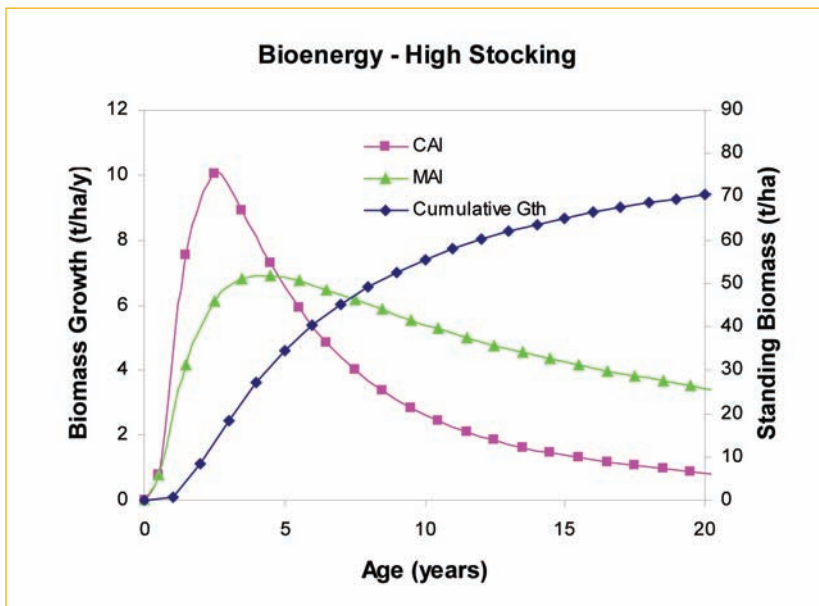


Figure 10-4: Growth curves used for modelling carbon mitigation for a short rotation forest showing current annual increment (CAI), mean annual increment (MAI) and total standing volume to 20 years.

Other assumptions include:

- The rotation length for the bioenergy plantation was assumed to be 10 years. Thus the total amount of biomass harvested every 10 years was 56 t/ha.
- Yield of electricity from biomass: 1.35 MWh/t, based on an assumed energy content of 16.2 GJ/t (DCC 2008) and a conversion efficiency of 30%.
- Emissions from biomass production: 100 kg CO₂-e/t based on emissions from woodchip production from softwood plantations (80 kg CO₂-e/t) adjusted for a shorter rotation length (10 years for a bioenergy plantation instead of 30 years for a sawlog plantation (May *et al.* In press). For the shorter rotation, emissions from harvest, transport and processing (60 kg CO₂-e/t) were assumed to be the same per tonne of wood, but emissions from establishment and plantation management (20 kg CO₂-e/t) were assumed to be doubled. Emission factors for non-CO₂ emissions were assumed to be 21 for methane and 310 for nitrous oxide.
- Non-CO₂ emissions from biomass combustion for bioenergy assumed to be 1.3 kg CO₂-e/GJ (equivalent to 21 kg CO₂-e/t; DCC 2008a).
- Thus, total emissions per unit bioenergy produced were estimated to be 121 kg CO₂-e/t wood used or 90 kg CO₂-e/MWh electricity generated.
- Emissions from conventional electricity production: 1040 kg CO₂-e/MWh (DCC 2008a). Thus, the net mitigation benefit of substituting bioenergy from wood for conventional electricity production was estimated to be 950 kg CO₂-e/MWh or 1280 kg CO₂-e/t wood.

The cumulative effect on greenhouse gas emissions under this scenario for a single stand harvested every 10 years for bioelectricity production is illustrated in Figure 10-5. As the forest grows it stores carbon in the standing biomass at a rate of around 10 t CO₂-e/ha/year (green line). Every 10 years, the total biomass (56 t/ha containing 97 t CO₂-e carbon) is harvested and converted to bioenergy with a total net benefit in terms of offsetting greenhouse gas emissions from conventional electricity production of 71 t CO₂-e. This process can be repeated indefinitely resulting in a cumulative benefit of over 700 t CO₂-e/ha over 100 years.

For comparison, total carbon sequestered in an unharvested forest was also modelled. The same growth parameters were assumed for this stand as for the bioenergy plantation. Thus, after an initial period of relatively fast growth for the first 15 years, in which a total of 120 t CO₂-e/ha carbon was sequestered, the rate of growth slowed considerably with only an additional 35 t CO₂-e/ha carbon fixed over the next 85 years. Thus, the total amount of carbon emissions mitigated by the unharvested forest after 100 years was less than one quarter of that for the bioenergy plantation.

At an estate level, the annual rate of GHG mitigation depends on the rate of planting and the total area to be planted as well as the annual rate of carbon mitigation per hectare of land planted. The annual GHG reduction for a total estate of 2 Mha planted at a rate of 50,000 ha/y based on the same growth rate and rotation length as the single stand is shown in Figure 10-6. The annual rate of GHG mitigation associated with storage of carbon in the standing forest increases as the planted area expands until 10 years when

harvesting commences. As the planted area increases, the annual rate of carbon sequestration in the standing biomass fluctuates between 0 and 4.8 Mt CO₂-e/y until the total estate has been planted and harvesting reaches sustainable yield at age 40 years. After this time there is no further increase in average standing biomass and thus no increase in carbon stocks across the estate. However, energy production from the harvested biomass provides ongoing GHG mitigation with the annual rate increasing over time as the area harvested increases. This reaches a sustainable level of 14 Mt CO₂-e/y at age 40 years.

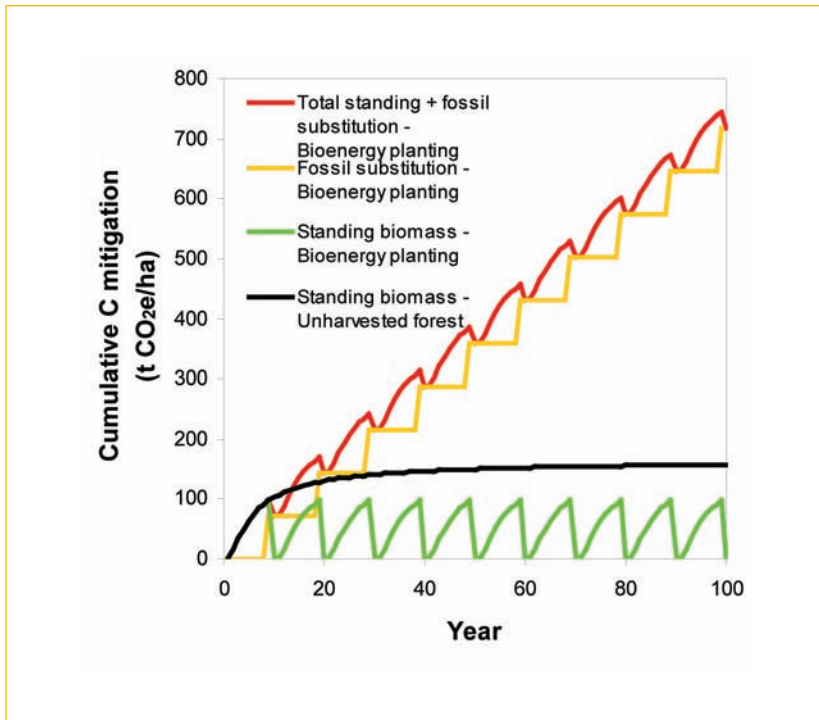


Figure 10-5: Cumulative effects on greenhouse gas emissions of a short rotation forestry stand harvested every 10 years compared with an unharvested forest.

In comparison, in the unharvested plantation, the rate of increase in carbon stocks increases over time as the planted area expands, reaching a maximum of 7.2 Mt CO₂-e/y at 40 years. After planting ceases, the annual increase in carbon falls rapidly as a result of the decline in current annual increment with increasing stand age (see Figure 10-4). Thus the net increase in carbon stocks across the estate at 60 years is just 14% of that at 40 years.

The cumulative effect of the short rotation bioenergy planting and an unharvested stand on GHG emissions is shown in Figure 10-7. This shows the average carbon stock of short rotation plantings increasing to a maximum of 100 t CO₂-e at 40 years, while that of an unharvested stand gradually increases to 308 t CO₂-e by 100 years. However, the total effect of bioenergy production on GHG emissions continues to increase over time in a linear fashion from age 30 onwards, reaching 1185 Mt CO₂-e by 100 years. Thus, the total mitigation effect of bioenergy plantations after 100 years is more than triple that of an unharvested forest covering the same area.

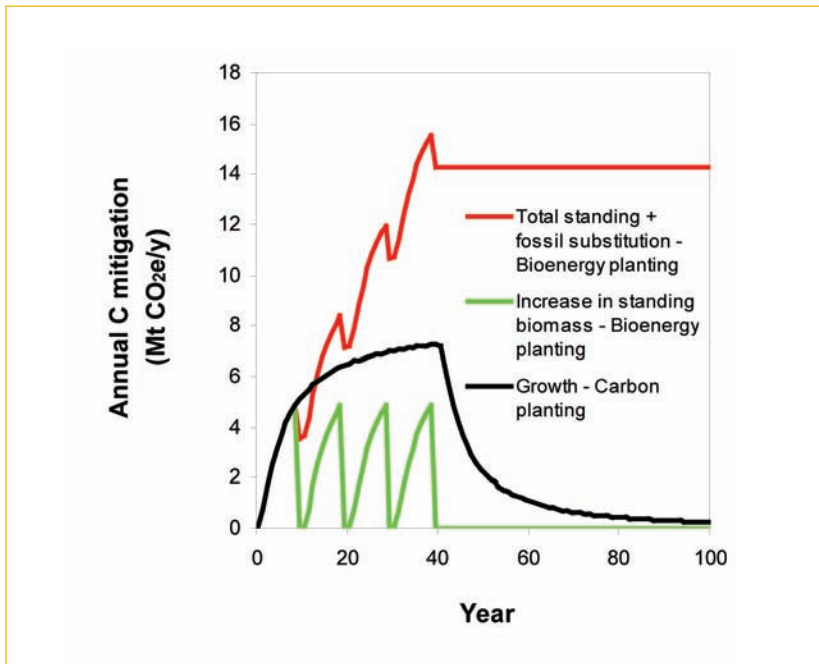


Figure 10-6: Annual mitigation of short rotation forestry plantings planted at a rate of 50,000 haly (up to 2 million ha) and harvested and used for electricity production after 10 years compared with an unharvested stand.

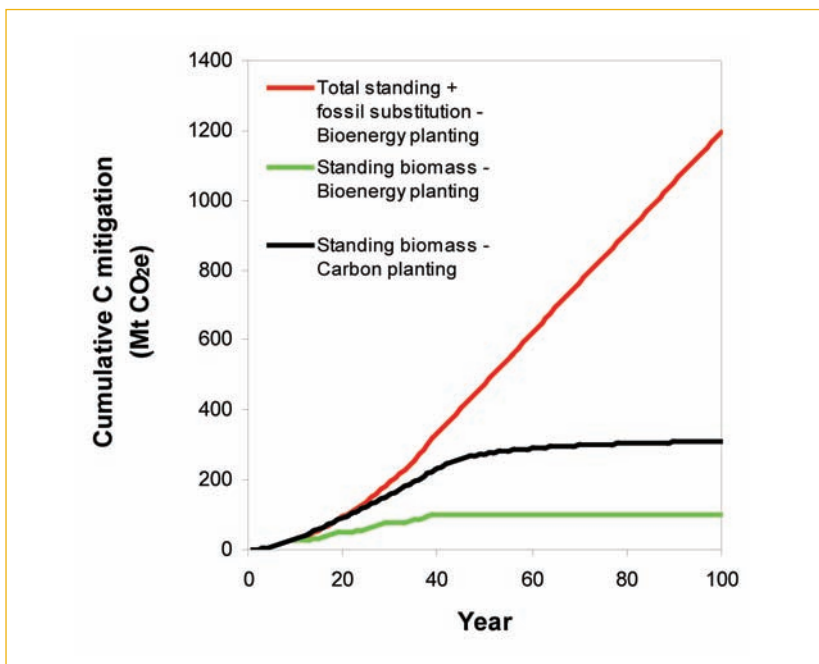


Figure 10-7: Cumulative mitigation by short rotation plantings planted at a rate of 50,000 haly (up to 2 million ha) and harvested and used for electricity production after 10 years compared with an unharvested stand.

The scenarios modelled here are only two of the myriad of possible alternatives. Increased initial planting density will tend to increase initial growth at the expense of longer term growth, while increased rates of harvesting (i.e. shorter rotation lengths) will tend to increase the potential biomass production from a bioenergy system, but will also increase the need for fertiliser and may reduce harvesting efficiency (in terms of tonnes biomass per litre of fuel used) and thus increase emissions from the short rotation bioenergy system. Higher mitigation rates may also be achievable if some of the harvested plantings are converted into biochar:

The results of a sensitivity analysis of the effect of varying key parameters of the short rotation and unharvested plantation scenarios are shown in Table 10-8. The most important factors in terms of determining net cumulative mitigation of greenhouse gas

emissions were maximum potential growth (varied by changing site productivity) for both bioenergy and unharvested plantations and maximum age of growth (varied in practice by changing initial stocking) and rotation length for the bioenergy plantations. Since emissions from growing, harvesting and transporting the biomass represent only a small proportion of the total carbon mitigation effect (~10%), varying these had little impact on the total greenhouse gas benefit of bioenergy plantations.

These results show that the long term carbon mitigation benefits of bioenergy plantations are likely to be far greater than those of unharvested forest for a given site. However, it is important to match stocking for bioenergy plantings with rotation length in order to optimise the long term carbon capture for a site. This will include taking other factors into consideration including risk of mortality due to drought, nutrient and water requirements, establishment costs and harvesting method.

Table 10-8: Result of sensitivity analysis of the effect of increasing or decreasing key variables in the scenarios by 50% on the resultant mitigation of greenhouse gasses on a per hectare basis over 40 years.

Plantation system and variable	Variable Value			Cumulative CO ₂ sequestered by 2050 (t CO ₂ -e/ha)					
	Original	+50%	-50%	Original	+50%		-50%		
					Value	Change	Value	Change	
Bioenergy Plantation									
Max potential volume	t/ha	90	135	45	287	431	50%	143	-50%
Age of Peak Growth	years	3	4.5	1.5	287	213	-26%	388	35%
Rotation Length	years	10	15	5	287	271	-6%	357	24%
CO ₂ emissions	kg CO ₂ -e/t	121	182	61	287	274	-5%	301	5%
Unharvested Forest									
Max potential volume	t/ha	90	135	45	147	220	50%	73	-50%
Age of Peak Growth	years	3	4.5	1.5	147	136	-7%	158	7%

10.10 Lateral Thinking

There are a range of technologies and options which have not been discussed here. There are many opportunities in the area of conversion technologies and various strategies for their deployment which have not been discussed at all — ranging from off-grid small scale gasifiers or pyrolysis plants which can produce fuel, electricity and biochar (See Chapter 11). There are biorefinery options emerging for high value products with bioenergy (fuel, heat, power) as a coproduct. There are Combined Heat and Power (CHP) systems being developed overseas which, when deployed in closed loop systems with industry and housing, claim up to 90% conversion efficiencies for biomass which would raise the mitigation benefits substantially over those estimated here. Biomass fired power stations could use geo-sequestration technologies developed for coal-fired power stations, and thus amplify greatly the sequestration and mitigation benefits. The potential for biorefineries to produce high value food products or additives or other high value industrial products (e.g. petrochemical replacements), along with heat, power or liquid fuel is the subject of intense research in the international environment, although Australia is lagging behind in such efforts (Haritos 2007).

The options of combined food and fuel production farms (e.g. oil mallee alley planting systems or grass/cereal systems) have not been explored in this report and may be well suited to conditions in Queensland. While one scenario for short rotation forestry has been presented, there may be many ways to optimise this type of production system which have not been presented here. Grasses show good potential for biofuel production as well as low inputs and high sinks in soil carbon, but this avenue of research is in the very early days in Australia. There are a number of Australian native species of woody and grass species which may lend themselves to bioenergy production in low productivity land, perhaps with high value chemical constituents, but again, these avenues of research are in very early days. Large scale planting of *Pongamia pinnata*, an oilseed legume tree, shows potential but is not presented here due to lack of reliable growth, yield and emissions data on which to base analysis. Likewise, a small subset of the potential algal opportunities has been presented, again due to lack of reliable data on which to base analyses.

Other options include reduction of emissions from forestry plantations (including bioenergy plantations) by planting nitrogen fixing species and reducing nitrogen fertiliser use and optimising production systems to maximise biomass (rather than food or fibre) production. The likely costs (in terms of both reduced production of current products such as sugar or timber; increased land-use intensity and, potentially increased emissions associated with production) need to be quantified and weighed against the benefits in terms of increased feedstock production for energy.

There is great potential for lateral thinking in the area of biomass production but due to limited data with good reliability in Australia, only a small subset of these have been explored in this report. In particular, while this chapter has reported on some of the current feedstocks with some reliability, the options for future feedstock production systems (short rotation forestry, mallee cropping, native woody and grass species and algae) as well as future third generation (biorefinery) conversion systems which may be able to derive high value food and industrial products as well as heat, power and liquid fuel have not been adequately explored here. A more robust analysis than provided here could be underpinned by improved:

- LCAs which include the full set of consequences of diverting biomass to biofuel (i.e. consequential rather than attributional LCA).
- Paramaterisation of emissions for various production systems especially soil carbon run-down, nitrous oxide and methane emissions.
- Understanding and parameters for the production and agronomy and emissions of new and novel systems (e.g. algae, short rotation forestry in different land areas, oilseed trees such as *Pongamia*).
- Analysis of future land use change options.
- Analysis of yields and emissions of various conversion pathways, with an improved incorporation of error and uncertainties through the full pathways.
- Economic analysis through all the above.

Table 10-9: Scenario settings for First Generation Biofuels.

Feedstock	Cereals Grain			Product	Biofuel
	Max utilisation t/yr	Current utilisation %	Final utilisation %	Time to start years	Time to full utilisation years
Business as Usual (min)	900,000	0%	10%	0	10
Business as Usual (max)	3,610,000	0%	10%	0	10
Potential (min)	1,350,000	0%	100%	0	20
Potential (max)	7,220,000	0%	100%	0	20
Attainable (min)	900,000	0%	20%	0	20
Attainable (max)	5,415,000	0%	20%	0	20

Feedstock	Oilseed Seed			Product	Biofuel
	Max utilisation t/yr	Current utilisation %	Final utilisation %	Time to start years	Time to full utilisation years
Business as Usual (min)	128,800	0%	10%	0	10
Business as Usual (max)	468,800	0%	10%	0	10
Potential (min)	266,000	0%	100%	0	10
Potential (max)	937,600	0%	100%	0	10
Attainable (min)	128,800	0%	20%	0	10
Attainable (max)	703,200	0%	20%	0	10

Feedstock	Sugarcane C-Mol			Product	Biofuel
	Max utilisation t/yr	Current utilisation %	Final utilisation %	Time to start years	Time to full utilisation years
Business as Usual (min)	665,000	5%	75%	0	5
Business as Usual (max)	988,000	5%	75%	0	5
Potential (min)	684,000	5%	100%	0	20
Potential (max)	1,066,000	5%	100%	0	20
Attainable (min)	665,000	5%	100%	0	20
Attainable (max)	1,040,000	5%	100%	0	20

Feedstock	Sugarcane Sugar			Product	Biofuel
	Max utilisation t/yr	Current utilisation %	Final utilisation %	Time to start years	Time to full utilisation years
Business as Usual (min)	3,150,000	0%	0%	0	5
Business as Usual (max)	4,788,000	0%	0%	0	5
Potential (min)	3,240,000	0%	100%	0	20
Potential (max)	5,166,000	0%	100%	0	20
Attainable (min)	3,150,000	0%	20%	0	20
Attainable (max)	5,040,000	0%	20%	0	20

Table 10-10: Scenario settings for bio-electricity were the same as for syndiesel except a) current utilisation of sugarcane bagasse was estimated to be 25% and b) the time to start was assumed to be 0 years for cereal stubble, wood waste, sugarcane bagasse and forest sawmill residue.

Feedstock	Cereals Stubble			Product	Syndiesel
	Max utilisation t/yr	Current utilisation %	Final utilisation %	Time to start years	Time to full utilisation years
Business as Usual (min)	1,638,000	0%	5%	5	10
Business as Usual (max)	6,798,300	0%	5%	5	10
Potential (min)	2,535,000	0%	100%	5	20
Potential (max)	13,596,600	0%	100%	5	20
Attainable (min)	1,638,000	0%	50%	5	20
Attainable (max)	10,197,450	0%	50%	5	20

Feedstock	Waste Wood Waste			Product	Syndiesel
	Max utilisation t/yr	Current utilisation %	Final utilisation %	Time to start years	Time to full utilisation years
Business as Usual (min)	93,489	0%	0%	5	10
Business as Usual (max)	224,753	0%	0%	5	10
Potential (min)	209,203	0%	100%	5	20
Potential (max)	587,028	0%	100%	5	20
Attainable (min)	161,767	0%	80%	5	20
Attainable (max)	315,785	0%	80%	5	20

Feedstock	Algae			Product	Syndiesel
	Max utilisation t/yr	Current utilisation %	Final utilisation %	Time to start years	Time to full utilisation years
Business as Usual (min)	0	0%	100%	5	10
Business as Usual (max)	0	0%	100%	5	10
Potential (min)	600,000	0%	100%	5	20
Potential (max)	2,000,000	0%	100%	5	30
Attainable (min)	200,000	0%	100%	5	30
Attainable (max)	1,000,000	0%	100%	5	40

Feedstock	Sugarcane Bagasse			Product	Syndiesel
	Max utilisation t/yr	Current utilisation %	Final utilisation %	Time to start years	Time to full utilisation years
Business as Usual (min)	3,937,500	0%	50%	5	20
Business as Usual (max)	5,985,000	0%	50%	5	20
Potential (min)	4,050,000	0%	100%	5	20
Potential (max)	6,457,500	0%	100%	5	20
Attainable (min)	3,937,500	0%	50%	5	20
Attainable (max)	6,300,000	0%	50%	5	20

Feedstock	Forest Sawmill Residue			Product	Syndiesel
	Max utilisation t/yr	Current utilisation %	Final utilisation %	Time to start years	Time to full utilisation years
Business as Usual (min)	530,607	0%	10%	5	30
Business as Usual (max)	738,230	0%	10%	5	30
Potential (min)	612,607	0%	100%	5	15
Potential (max)	861,120	0%	100%	5	15
Attainable (min)	760,703	0%	50%	5	20
Attainable (max)	1,511,769	0%	50%	5	20

Feedstock	Forest Harvest Residues			Product	Syndiesel
	Max utilisation t/yr	Current utilisation %	Final utilisation %	Time to start years	Time to full utilisation years
Business as Usual (min)	207,057	0%	5%	5	30
Business as Usual (max)	856,875	0%	5%	5	30
Potential (min)	233,023	0%	100%	5	15
Potential (max)	938,575	0%	100%	5	15
Attainable (min)	305,014	0%	50%	5	20
Attainable (max)	1,286,408	0%	50%	5	20

Feedstock	Forest Pulpwood			Product	Syndiesel
	Max utilisation t/yr	Current utilisation %	Final utilisation %	Time to start years	Time to full utilisation years
Business as Usual (min)	357,874	0%	0%	5	40
Business as Usual (max)	503,830	0%	0%	5	40
Potential (min)	319,900	0%	100%	5	20
Potential (max)	585,900	0%	100%	5	20
Attainable (min)	1,230,293	0%	50%	5	30
Attainable (max)	2,458,219	0%	50%	5	30

Feedstock	Forestry Bioenergy Pltn			Product	Syndiesel
	Max utilisation t/yr	Current utilisation %	Final utilisation %	Time to start years	Time to full utilisation years
Business as Usual (min)	0	0%	100%	20	50
Business as Usual (max)	0	0%	100%	20	50
Potential (min)	6,000,000	0%	100%	10	20
Potential (max)	27,000,000	0%	100%	10	40
Attainable (min)	1,500,000	0%	100%	15	30
Attainable (max)	9,000,000	0%	100%	15	45

10.11 Contributors

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10.12 Research groups

A wide range of Australian research groups are focussed on the use of biomass. This list is not comprehensive, but covers some of the major research activities:

CSIRO Energy Transformed Flagship:

- Biofuels research stream — biomass production assessment, screening new and novel terrestrial species and production systems, systems analysis and sustainability assessment (including Life Cycle Assessment or LCA), novel enzymatic and thermo-chemical production pathways, algae screening, system design and engineering for algal ponds.

Co-operative Research Centre (CRC)

- Future Farm Industries — screening range of woody perennial species, oil mallee systems including growing, sustainability, harvesting and conversion to products, novel products in woody and forage plants.
- CRC for Sugar Industry Innovation through Biotechnology — including methods to estimate the environmental impact of products from sugar industry product diversification, including ethanol and lignin through LCA.

Universities

- Queensland University of Technology — NCRIS at Mackay.
- University of Queensland — *Pongamia pinnata* as a future feedstock, hydrogen production from algae.
- Southern Cross University — specialist skills in grass genetics, looking to lead a bid for a Biofuels CRC.
- Flinders University — biofuels production, economic and environmental sustainability of a novel value-adding biorefinery approach, research into second generation biofuels, bioproducts, biorefinery technologies and management.

Other

- South Australian Research and Development Institute (SARDI) — Mustard as a potential biodiesel feedstock, an NCRIS photo-bioreactor facility for algae research.
- BEAM Research Network, convened by Murdoch University — biotechnological and environmental applications of microalgae including the potential for renewable fuels such as hydrogen and biodiesel.

10.13 Research activity and focus

Biofuels and bioenergy research is a burgeoning area due to the recognition that renewable energy and fuels are critical for reduction in GHG emissions. The international research budgets in the biofuels and bioenergy areas dwarf those in Australia. The areas comprise a vast agenda of research topics from sourcing different types of feedstock in existing forestry, agriculture and waste systems; assessing new and novel feedstocks; enzymatic and thermo-chemical conversion technologies for fuels; small scale off-grid gasification; biorefineries for energy and bioproducts; economics and policy issues; Life Cycle Assessments (LCAs) for various production pathways; and scaling up both biomass production and second generation conversion technologies in a cost effective manner.

Sustainability is a threshold issue for the industry, and the development of a system to assess and claim recognised sustainability credentials will be an important industry enabler. The Research and Development needs for biofuels, bioenergy and bioproducts in Australia were clearly set out in O'Connell *et al.* (2007b).

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Table 10-1 I: Methodology for estimating potential, attainable and base greenhouse gas sequestration/mitigation for biofuels.

Option		Biofuels first generation
		Biofuels second generation
		Bioelectricity second generation
Business as Usual Net Carbon Mitigation/Storage (Mt CO ₂ -e) from 2010 to 2050		10–20 Mt
		50-90 Mt
		80–130 Mt
Net Potential* Carbon Mitigation/Storage (Mt CO ₂ -e) from 2010 to 2050	Australia	-
	Queensland	110–290 Mt
		5 Mt/yr
		380-1060 Mt
		18 Mt/yr
	510–1430 Mt	
	24 Mt/yr	
Functional Unit and Basic Algorithm Used to Calculate per Unit CO ₂ -e		Functional unit (ha). Cereals and sugar for ethanol. Oilseeds for biodiesel. Area (ha) × yield (t/ha) = total production (t) Conversion of total production (t) × conversion rate (l/t) = biofuel (l) Mitigation from fossil fuel substitution by biofuel with offsets calculated against petrol (for ethanol), diesel (for biodiesel).
		Functional unit (ha). Cereals and sugar for ethanol. Oilseeds for biodiesel. Area (ha) × yield (t/ha) = total production (t) Conversion of total production (t) × conversion rate (l/t) = biofuel (l) Mitigation from fossil fuel substitution by biofuel with offsets calculated against petrol (for ethanol), diesel (for biodiesel).
		Functional unit (ha). Area (ha) × yield (t/ha) = total production (t) Conversion of total production (t) × conversion rate (l/t) = biofuel (l) Mitigation from coal-based electricity generation by bioelectricity with offsets calculated against emissions from current Qld. electricity mix for combined potential feedstock production of stubble, wood waste, bagasse, sawmill and forestry residues, plantation pulpwood, bioenergy plantations and algae.

Scaling Up Process	<p>Increased production base (from 1.8–3.0 million ha to 2.4–5.2 million ha). Plus increased utilisation (from an average 12% to 100%) providing a total of 2.6-6.2 ML biofuel by 2030.</p> <hr/> <p>Total production of feedstock increasing from 7–15 Mt/y to 15-52 Mt/y by 2050, as a result of expanded production base (mainly bioenergy plantations which increase to 0.8-1.5 million ha or 3-6% of cleared non-agricultural land) and an increase in the proportion of all potential feedstocks allocated to biofuel production, from 25 % in the BAU scenario to 100% by 2050, producing a total of 2.2–7.3 GL/y syndiesel, 1.4-4.8 GL/y syngasoline and 4-14 TWh/y bioelectricity.</p> <hr/> <p>Total production of feedstock increasing from 7–16 Mt/y to 10–30 Mt/y by 2050, as a result of expanded production base and an increase in the proportion allocated to bioenergy, producing a total of 16–60 TWh/y electricity.</p>
Attainable* Net Carbon Mitigation/Storage (Mt CO ₂ -e) and factors driving this translation	<p>Queensland</p> <p>30–60 Mt CO₂-e over 40 years, based on a production base of 1.7–4.0 million ha and a utilisation rate of 20% for grain, oilseed and sugar and 100% for C-molasses, giving a total biofuel production from of 0.7–1.4 GL/y by 2050. Ave 1 Mt/yr</p> <hr/> <p>130–420 Mt CO₂-e over 40 years, based on a production base of 2–5 million ha and an average utilisation rate of 64 % for combined feedstocks giving a total biofuel production of 0.8-3.1 GL/y syndiesel, 0.6-2.0 GL syngasoline, 0.1-0.5 GL/y biodiesel (from algae) plus 2-6 TWh/y bioelectricity by 2050. Ave 6.9 Mt/yr</p> <hr/> <p>200–590 based on a production base of 2–5 million ha and an average utilisation rate of 70% for combined feedstocks giving a total bioelectricity production of 6–24 MWh/y by 2050. Ave 9.9 Mt/yr</p>

* See Chapter 1 Section 1.2 Methodology for explanation of potential, attainable and base.

11 Stabilisation of organic carbon in soil through biochar production

Evelyn Krull

11.1 Definition and Scope

Biochar is a charcoal-like material that has potential for climate mitigation, improved land and soil productivity and production of renewable energy. It is produced from the pyrolysis of organic matter (heating to between 350-600°C under limited oxygen). The process converts more easily-decomposable ('unstable') organic matter into a highly stable (i.e. biologically and chemically stable) form of carbon.

Biochar is the solid by-product resulting from bioenergy production (Figure 11-1). The pyrolysis conditions can be optimised for bioenergy or biochar production. Biochar qualities can also be tailored for desired properties (e.g. high stability, high adsorptive capacity, increased cation exchange capacity, high nutrient content) through selection of feedstock and processing conditions. Waste products that would otherwise end up in landfill are the most desired feedstocks for biochar production i.e. it would be not advisable to convert otherwise valuable materials (e.g. high quality wood or compost) into biochar as they have qualities that make them more suitable for other usage if not pyrolysed. Conversely, waste feedstocks need to be checked for toxins (e.g. heavy metals) which may occur in some biosolid materials or treated wood products.

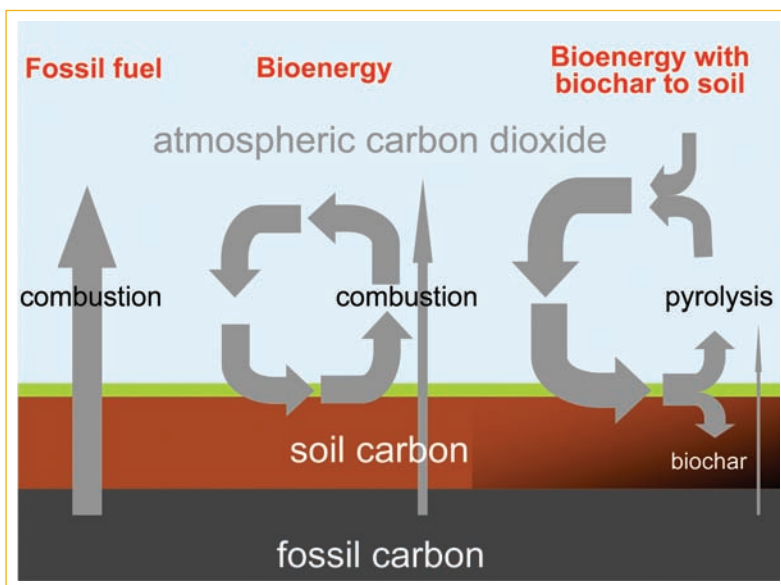


Figure 11-1: Biochar, especially when combined with bioenergy production can result in net removal of carbon from the atmosphere.

There are several benefits associated with the production and usage of biochar:

Firstly, biochar and coproduced bioenergy from urban, agricultural and forestry biomass has the potential to help combat climate change by (a) displacing fossil fuel use, (b) sequestering C (c) potentially decreasing N_2O and CH_4 emissions from soils, (d) avoiding emissions of CH_4 produced from landfill, (e) reducing energy requirements for soil tillage, (f) increasing C sequestration by plants through increased crop vigour and (g) reducing emissions associated with the manufacture of fertiliser.

Secondly, biochar used as a soil amendment can have beneficial effects for plant production as it may (a) reduce soil acidity, (b) increase or retain plant productivity with a lower amount of fertiliser use and (c) more efficiently retain nutrients and avoid leaching from the soil profile.

Thirdly, biochar may enable soil and vegetation to adapt to climate change by (a) increasing water holding capacity of soils, and (b) increase soil pliability and increasing water infiltration.

Together, biochar production and its utilisation results in a C negative greenhouse gas balance: it removes CO_2 from the atmosphere

and converts it into a highly stable form of C, and produces additional mitigation benefits as listed above, such that the net mitigation benefit is greater than the CO₂-equivalent in the biomass utilised .

Figure 11-2 illustrates that in the natural carbon cycle, plants absorb carbon as CO₂ from the atmosphere during photosynthesis. When the plant dies, the carbon-rich plant matter decomposes releasing carbon into the soil and back into the atmosphere, completing the cycle. If, however, instead of the plant matter decomposing it is used as the feedstock for pyrolysis there is the potential for the carbon to be removed from the cycle.

After undergoing pyrolysis, the carbon in the plant matter changes from being in an unstable and easily broken down form which will quickly return to the atmosphere, to being in the highly stable and hard to breakdown form of biochar. This means the carbon cannot readily re-enter the atmosphere but is sequestered, with the potential to reside in soil over decades, centuries, and even up to millennia. This long-term storage of carbon means that it is essentially removed from the active carbon cycle, hence biochar production, in conjunction with bioenergy production, is known as a carbon-negative process.

Biomass ('feedstock') for biochar production can comprise most urban, agricultural and forestry biomass such as wood chips, saw dust, tree bark, corn stover; rice or peanut hulls, paper mill sludge, animal manure and biosolids. Under controlled conditions (i.e. in a pyrolysis plant; Figure 11-3), about 50% of the carbon in biomass is converted to biochar while the remainder is used for the pyrolysis process and bioenergy (heat, steam, electricity) production, the exact ratios depending on the type of production (e.g. fast vs. slow pyrolysis), biomass source and set conditions of pyrolysis.

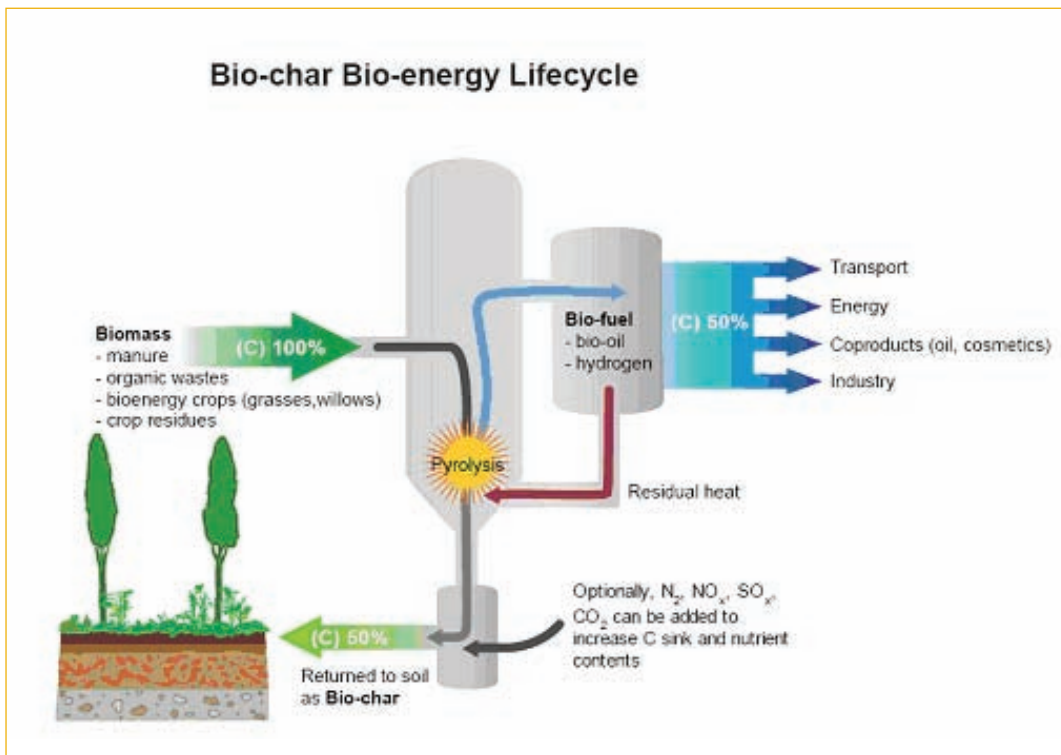


Figure 11-2: The combined process of biochar and bioenergy production, resulting in net carbon sequestration ("Carbon negative process").

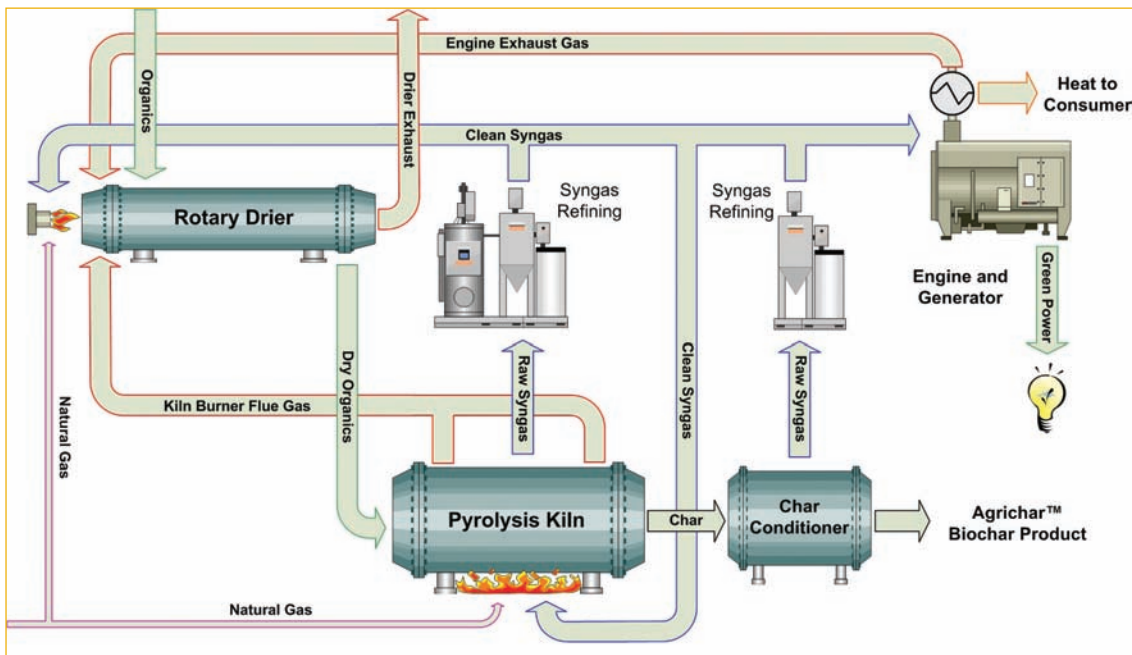


Figure 11-3: Illustration of slow pyrolysis combustion (courtesy of BEST Energies).

The scope of this study was to estimate the biochar production and sequestration potential for one major feedstock source in Queensland for which some production data was available. The feedstock chosen was sugar cane biomass – both trash and bagasse. There are many other feedstock sources in Queensland (biowaste, timber mill waste, municipal green waste) but at the moment there is no Queensland data and little reliable Australian data on yields and quality attributes of biochar produced from these feedstocks.

11.2 Analysis Section

What are the technologies/policies/management changes that will deliver?

Sustainable production of biochar occurs as part of bioenergy production from pyrolysis of sustainably-produced biomass, which may be in the form of thermal energy, synthesis gas ('syngas'; e.g. hydrogen, methane, carbon monoxide) or bio-oil. Yields of biochar are reduced when yield of energy obtained from the system is increased. However, as calculated by Gaunt and Lehmann (2008), while the energy gain decreases if biochar is added to soil instead of being burnt for further heat production and energy gain, the emission reductions by adding biochar to soil are much greater than the fossil fuel offsets when using the biochar as energy. In other words, if energy maximization is the key goal, then biochar should be used for further energy generation (mainly heat); however, if emission reductions and climate change mitigation through C sequestration is the aim, then biochar should be captured and added to soil. Additional analysis is required to assess the relative merit (in terms of CO₂-e benefit) of these two pathways and will be largely driven by the CO₂-e intensity of electricity production (i.e. coal versus green power production).

Specifically, taking into account the estimated increase in crop productivity through the application of biochar, the latter scenario becomes more economical, considering the potential savings in fertiliser costs and the energy required to produce fertilisers. However, at this stage we are hesitant to quantify the "crop productivity" due to the scarcity of reliable measured data to support these estimates and also its longevity.

What is the current status for this mitigation/sequestration opportunity?

Within Queensland, there is no current regulated production and application of biochar. While some feedstocks, such as sawdust, bagasse and rice hulls, are currently used as energy sources, the energy potential of second generation biofuels based on lignocellulosics is not exploited by pyrolysis in Queensland because the conversion technologies are not yet mature or commercially available, materials are not centrally located and supply chains have not yet been established. Some potential waste materials for biochar and biofuel production are listed in Table 11-1.

However, while bioenergy production relies on specific feedstocks to achieve adequate conversion efficiency, biochar can be produced from any biological biomass, preferably materials that would be considered waste materials. In order to ensure a C negative process (i.e. net sequestration according to a whole of life-cycle analysis) transport to and from the pyrolysis plant would need to be

minimised. A scenario where a group of sugar cane farmers would collectively purchase a small biochar plant which may be attached to the local mill, would ensure that transport of feedstocks and conversion to both energy and biochar occurs on a local scale and is of immediate benefit to the producing community. Interest among farmers is high and it is more the appropriate scoping through science of risk (maximum application rate) and quantification of benefits to soil that is needed rather than economic incentives to engage the farming community in its application. However, larger-scale pyrolysis plants would require assistance, in the first instance, from government in order to be run and implemented to allow a greater conversion of biomass to biochar. With regard to incentives for land-users and farmers, the prospects of increasing soil productivity would be a greater driver for usage of biochar than possible credits from C sequestration through an emissions trading scheme (ETS). This would also ensure that implementation, production and usage could occur independent of the ETS and would focus on soil amelioration rather than offsets from C sequestration.

Table 11-1: Summary of potential feedstocks for biofuel and biochar production in Queensland; Source: Queensland EPA (2002). For a more comprehensive list for feedstocks for biofuels, refer to Chapter 10 in this report.

Organic material for biochar or biofuel production	Tonnes year ⁻¹
Macadamia shells	6,800
Forestry Residue	2,800,000
Sawmill waste	1,400,000
Feedlot manure	380,000
Food processing waste	3,000
Bagasse from sugar industry	12,000,000
Cotton trash	22,000

Internationally, several countries (28 to date) have endorsed the use of biochar as a climate mitigation and C sequestration tool through a submission to the UNFCCC. For example, the Federated States of Micronesia (FSM) has led a submission to the United Nations Framework Convention on Climate Change (UNFCCC) to introduce biochar as a technology for consideration as a 'fast-start' strategy to mitigate climate change. The submission includes biochar on the draft agenda to be considered during the UNFCCC negotiations in Copenhagen in 2009. This is significant as it officially positions biochar as a mitigation technology prior to the post-2012 framework.

The submission by FSM follows the filing of a submission by the United Nations Convention to Combat Desertification (UNCCD) endorsing biochar. The UNCCD, a sister convention of the UNFCCC, identified biochar as a unique opportunity to address soils as a C sink. This is in line with its 10-year strategic program that calls for the promotion of low-C footprint sustainable practices and technologies.

According to the Intergovernmental Panel on Climate Change (IPCC 2006), biochar management would be a valid C sink in the current and post-2012 "Land Use, Land-Use Change and Forestry" (LULUCF) guidelines.

Current estimates of the stability of charcoal in soils range from centuries to millennia.

The mitigation benefits of biochar can be accounted for in several ways. Firstly, the renewable energy output would be counted as a reduction in greenhouse gas (GHG) emissions from the energy sector in national level emissions accounting. At the project scale, if implemented outside a capped sector, it could generate a credit for avoided GHG emissions, calculated from the displacement of fossil fuel energy. Recognition of reduced fossil fuel use, such as resulting from increased use of renewable energy, is a common feature of mandatory and voluntary emissions trading schemes.

Credit could also be claimed for avoided emissions from a change in the management of biomass, where the conventional management leads to emissions of CH₄ or N₂O. Several schemes recognize the benefit of avoided CH₄ emissions where waste is diverted from landfill (e.g., by NSW GGAS), or management of manure is improved (e.g., by RGGI).

Increase in soil C stock through biochar application could be recognized as an eligible sequestration activity. Theoretically it could be claimed under Kyoto Protocol Articles 3.3, 6 (J) and 12 (CDM), if applied to forest, or Article 3.4 if applied to agricultural land. However, modification of the standard methodology of estimating soil C (IPCC, 2006) would be required. Due to concerns about permanence and additionality, sequestration projects are often subject to strict criteria governing eligibility, estimation and reporting, which can escalate transaction costs and restrict participation. Difficulties in accurate monitoring of soil C due to spatial and temporal variation have been raised as barriers to inclusion of agricultural soil management in emissions trading. The VCS, for example, proposes a method requiring monitoring that involves sampling to prove the permanence of C stored in soil over time (VCS, 2007). However, in contrast, the CCX has successfully monetized soil C sequestration using conservative defaults to estimate sequestration

based on implementation of eligible management practices rather than monitoring soil C change (CCX, 2007b). Estimating soil C change due to biochar application could be based on an estimate of the quantity of C applied and the turnover rate, which should be much less uncertain than estimating impacts of tillage or grazing practices on soil C (Ogle *et al.* 2003).

An alternative approach could be taken to claiming credit for C captured and stored in biochar: rather than focusing on the increase in soil C stock, credit could be based on the avoided C emissions due to stabilizing organic matter. However, this approach would not readily fit within the offset rules of schemes currently operating, as most schemes do not recognize avoidance of CO₂ from biomass decomposition. One possible exception is the California Climate Action Registry (www.climateregistry.org), which recognizes ongoing storage of C in wood products. Under this scheme a claim for credit for ongoing storage of C in biochar as a component of the wood products pool may be accepted (this has not been tested, and would be applicable only where biochar is created from wood obtained from eligible forests).

The reduction in agricultural emissions resulting from application of biochar to agricultural land is also tradable. Under Article 3.4 of the Kyoto Protocol, increased sequestration in plants and soil resulting from biochar-induced enhancement of productivity could be credited.

In conclusion, assessment of the various schemes indicates that pyrolysis of biomass for bioenergy and biochar could be claimed through various routes: credit for bioenergy is widely recognized; credit for increasing C stocks in the soil, if biochar is applied to an eligible forest, is recognized by several schemes; avoided landfill emissions, and avoided emissions from manure could be claimed under a few schemes; one scheme recognizes agricultural management of soil C, and one recognizes long-term storage in wood products, either of which could provide an avenue to crediting the benefit of pyrolysis in stabilizing organic matter.

11.3 What is the potential to improve on this?

From an international treaty perspective, there is the potential for biochar to be included in a post-Kyoto Protocol, and this is endorsement by the UNFCCC, but would require the following policy action.

Policy action, specifically:

- Raising awareness on the role of land mitigation and adaptation to climate change and in particular the importance of biochar in enhancing the sequestration of C in soils
- Inclusion of biochar in clean development mechanisms (CDMs), an arrangement under the Kyoto Protocol, along with currently already included afforestation and reforestation (A/R).
- Revision of the additionality rules in order to take into account the fact that biochar is a C pool that is much more stable than any other non-geologic pool and that has more value than the potentially reversible A/R.
- Increase the level of Certified Emission Reductions (CERs), issued by CDM projects, that an annex I party can use towards meeting the Kyoto Protocol targets from the current 1% to a higher percentage. This would likely result in larger financial flows for both mitigation and adaptation.

11.4 What are the investments required within Australia?

- Biochar production: there are currently not enough commercial production facilities to produce enough quantities of biochar to ensure that the CO₂-e potentials can be achieved.
- Quality controls: Currently, there is no regulation of biochar production, no standards with regard to production (pyrolysis), types of adequate feedstocks, and biochar qualities or quality assessment. In order to ensure that adequate feedstocks are used and toxic-free biochar materials are generated in a sustainable (C negative) production process, a minimal set up of production and quality control standards need to be developed.
- Risk assessment: prior to biochar application to soil, it is necessary to ensure that maximum application rates are known, and that estimates can be made with regard to the likely increase in soil productivity. Also, biochar standards need to ensure that toxic-free feedstocks are used and that biochar is generated in a pyrolysis plant (i.e. not open-pit combustion). The term 'biochar' should be reserved for the use in this context and defined as such to ensure that production of any char material (possibly unsustainable) can be claimed to be 'biochar'.

11.5 Lead time to implementation

In Australia, several groups are currently working on commercial application; Rainbow Bee Eater Group in WA, Crucible Carbon and BEST Energies in NSW and EPRIDA in Vic. Commercial application may occur regardless of the outcomes at Copenhagen, or even local policy decisions, as economic viability may be possible through income from energy, waste mitigation and biochar sales as well as through the increase in soil productivity.

Currently, there is only a limited amount of biochar commercially available in Australia, but in some instance the feedstock source for pyrolysis is off-shore, i.e. rice hulls from the Philippines. There are now small biological fertiliser companies that are exploring the use of biochar as both an inoculant carrier as well as a source of minerals.

11.6 Defining Uncertainty

There is uncertainty associated with the level of feedstock production, the conversion to biochar with concomitant production of electricity from heat, and the stable C component in the biochar.

Once produced, the rate of turnover of biochar carbon is the major determinant of its value in long term sequestration of carbon. Very little is known about turnover rate of naturally-produced or manufactured biochar. Some studies show that natural charcoal in soil is inert and can persist for thousands of years but there is uncertainty over the turnover rate of synthetic biochar. Studies suggest that some synthetic biochars, produced from wood, have a mean residence time of thousands of years, though other biochars, such as those from poultry litter, decompose much more rapidly (Singh and Cowie pers comm.). Figure 11-4 summarises the end-member qualities of biochar as well as the pathway of production.

Biochars produced at higher temperature are more stable than those pyrolysed at low temperature. There is sufficient evidence to be confident that over 90% of the carbon in biochar produced from wood at temperatures in excess of 500°C will be stable for a minimum of 100 years (this estimate is likely to be exceeded by 5 to 10 times once more data are available to consolidate these numbers). Therefore, although the turnover rate in different situations is not known precisely, there is sufficient confidence in the permanence of some biochars for emissions trading purposes. (In comparison, sequestration through reforestation is required to be maintained for 100 years in the NSW GGAS and 70 years in the Commonwealth's Greenhouse Friendly program.)

Actions to reduce uncertainty should include further studies on yields and chemistry biochars in different soil types and climatic zones. This should be a national effort. Specifically, we need more turnover studies to understand interaction between biochar, clay and native organic matter for different biochar types, and different climates. National trials with well-defined biochars are also important to understand the agronomic benefits of biochar.

It is also important to investigate the other areas of uncertainty in the calculation of mitigation benefits of the biochar process, particularly impact on N₂O and CH₄ emissions, impact on native soil organic matter, impact on plant growth, and reduction in fertiliser requirements.

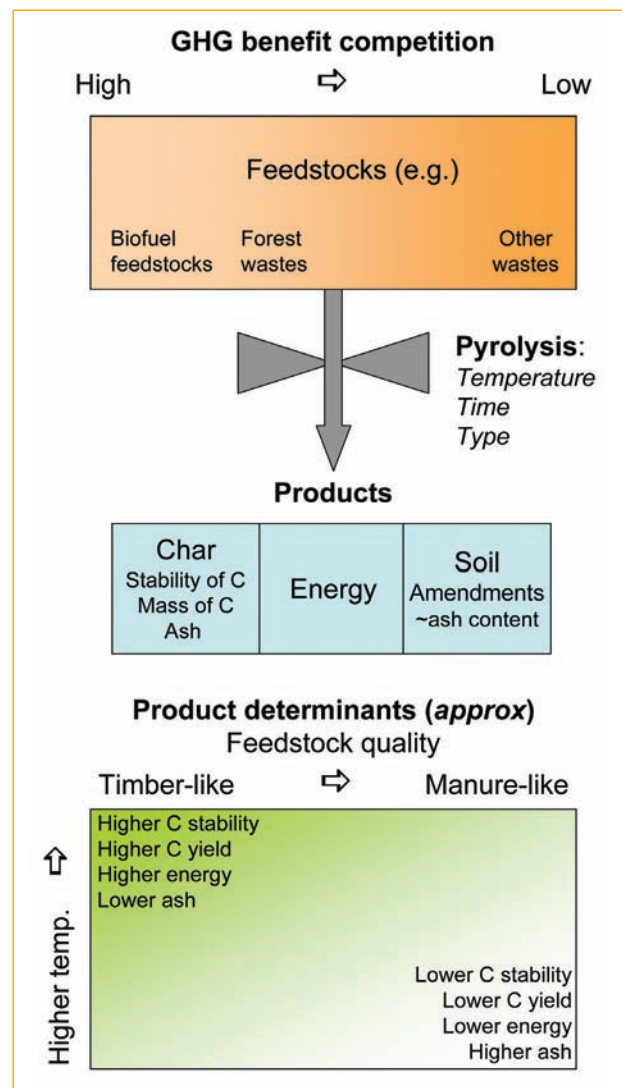


Figure 11-4: Summary of biochar production and qualities of biochars.

11.7 Risk and Barriers to Implementation

The main risks and barriers in the Australian context are the lack of endorsement (recognition and financial support) for specific biochar research to address key gaps in knowledge.

In order for biochar to be an effective greenhouse gas mitigation and soil amendment option, it is important to have pyrolysis plants in close proximity to both the source of feedstocks and site application (use in farms); otherwise, transport would offset the benefits of the sequestered C.

Currently the cost of biochar (due to the small number of commercial producers) is too high to make it attractive for farmers to invest in a large scale application of biochar. This also has contributed to some farmers producing their own 'biochar'. Unfortunately, this is often done in an uncontrolled combustion where a) gases are not captured, but released into the atmosphere, b) no control exists as to what type of feedstock is used (i.e. no control whether toxic substances may be concentrated in the final biochar product) and c) no control exists as to what temperatures are used and for how long the combustion took place which is important in determining the stability of biochar. Clearly it is important to ensure proper quality control of production of a product that is referred to as 'biochar'.

11.7.1 Additional Considerations

- We currently do not know how biochars will influence different soil types. So far, research points to sandy, acidic and/or low C content soils as having the greatest potential for showing positive effects for productivity increase. It is less likely for biochar to have significant agricultural benefit in Vertosols, high clay soils and soils with an inherently high fertility.
- We do not know how biochar properties change over time and what the likely long-term benefits may be. For example, some studies suggest that with time, biochar has the potential to developing more carboxyl groups which in turn can lead to a greater cation exchange capacity (CEC). A higher CEC is usually associated with greater nutrient retention, more efficient use of fertiliser and increased productivity. Other aspects to investigate further are liming potential and microbial effects (e.g. through providing a habitat for microbial growth).
- Barriers may include local legislation, relating to pyrolysis plant set-up, testing of emissions, biochars etc. It may be possible to convert coal-firing plants into biochar production units, but this needs to be investigated further.

Certainly many policy risk barriers exist, relating to acceptance of biochar into greenhouse gas emission trading schemes, but as mentioned before, this may not prove to be a barrier to widespread use of biochar because other aspects such as energy and agronomic benefit may be enough to drive the process.

Specific comments on biofuels for Queensland were part of an DERM (nee EPA) report in 2002. At the current time, low prices for electricity resulting from deregulation of the electricity market made the economics of green power production from biofuels unfavourable to the short-term establishment of this market (Queensland EPA 2002).

Although markets for renewable energy exist, the major limitations are the high costs of transporting the raw materials to a centralised processing site and the low returns for green power (Queensland EPA 2002).

A major constraint to industry development is the fragmented nature of the industries providing feedstock for pyrolysis and the disjunction between government departments responsible for management of waste material suitable for pyrolysis (Queensland EPA 2002).

One of the challenges facing the green waste industry is to modify or develop collection and separation systems to recover low-quality waste materials in a form that meets specification for pyrolysis and biochar production (Queensland EPA 2002).

11.8 Compliance and Auditing

Does the technology exist to measure mitigation/sequestration?

The technology exists but there are no standards, quality assurance or monitoring regulations in place which makes the implementation of a safe and environmentally-sustainable produced biochar product difficult. Currently there are too many unknowns to develop a reliable greenhouse gas accounting methodology.

Technologies exist to: Measure biochar production and define fossil fuel offsets; test biochar turnover rates/stability; and to test reduction in non-CO₂ GHGs. These cannot yet be operationally applied.

Test biochar turnover rates/stability

This still needs to be done in more detail and current estimates vary from 100s to several 1000s of years; however, it is sure that

biochar is stable over the next 100 years (one exception of biochar derived from poultry litter; which may turn over on a decadal scale Lehmann *et al.*, Singh and Cowie, 2008).

Test reduction in non CO₂ GHGs:

It has been observed and documented by van Zwieten (pers. com.) that some but not all types of biochars can yield to reduction of N₂O and CH₄ soil emissions in a limited set of conditions. More studies need to be done to quantify such effects.

Is it feasible to establish a monitoring and auditing system?

It is quite simple to document the conversion from biomass to biochar and the associated energy through monitoring and auditing of pyrolysis plants.

It will be necessary also to substantiate the fate of the biochar. If it is applied to soil, in most cases, it will remain partially stabilised for at least the next 100 years. This aspect would need to be modelled. However, it will be difficult to monitor and audit the other benefits of biochars – nitrous oxide emissions, soil strength effects, avoided landfill emissions as well as the long-term benefits of biochar (e.g. increase in cation exchange capacity with age).

Can the prediction of outcomes be modelled with enough precision?

If all the process parameters for the pyrolysis units used are known then it would be possible to model the outcomes. In order for reliable output from models, it is necessary that the pyrolysis process data are known at the scale of implementation as they may vary according to their specific use, i.e. maximisation for bioenergy or biochar production. The associated components of climate mitigation can be predicted with adequate precision, for example: quantity of fossil fuel offset through renewable energy and the quantity of carbon converted to biochar. Examples for the global benefits of biochar have been made by the International Biochar Initiative (IBI) (www.biochar-international.org). But such carbon stock effects have a high degree of uncertainty. There is a very high uncertainty in prediction of increased photosynthesis, the potential for reduction in non-CO₂ greenhouse gases from soil and avoided emissions of CH₄ from land filling of C.

Are there current accounting protocols or do new ones need to be considered?

Counting stabilisation of biomass C through addition to soil will require Australia to elect Article 3.4 of the Kyoto Protocol and the CPRS to include soil C management, either as an offset (before 2015) or through coverage of the agricultural sector (after 2015). There are no estimation methods specifically for biochar but it should be possible to adapt the methods used for organic amendments.

Alternatively counting stabilisation as avoided emission would require a fundamental shift in the accounting framework for annual biomass. The sequestration of carbon by annual plants is currently treated as carbon neutral. In order to count this avoided emission the removals and emissions from annual plants would have to be counted.

Measures of non-CO₂ greenhouse gas emissions will have to be modified for the use of biochar; for example, methods for estimating methane emissions from landfills exist and these could be used for calculating avoided emissions through the combustion of a proportion of these landfill materials to biochar. However, no parameters exist to account for the effects of biochar addition.

11.9 Other Benefits and Consequences

The other main ecological benefits of biochar use in Queensland, apart from C sequestration are threefold:

- Soil amelioration: Queensland soils, especially the ones under long-term sugar cane production, tend to be often acidic and low in organic C, demanding a high degree of management (e.g. lime addition) to combat further deterioration in pH. Biochar applied to these soils as part of a climate mitigation effort to store C, would have added benefits of decreasing soil acidity (due to the potential effect of liming and increased buffering capacity of biochar) as well as increasing water-holding capacity and increased nutrient use efficiency.
- Uptake of pesticides and nutrients from waterways. Due to sediment and nutrient transport from agricultural catchments to the Great Barrier Reef, algal blooms and increased turbidity are a real threat to the marine ecosystems. Biochar additions to the water ways may help bind and sequester nutrients and decrease turbidity due to its inertness and sterile nature. As natural-derived char is a normal component of Queensland estuaries, char additions may benefit ecosystems.
- Waste reduction. In the Burdekin alone 1 million ton of cane waste per year incurs costs for waste management if not being utilised after green harvest

Development of a biochar industry has the potential to diversify business in agriculture to include carbon sequestration and bioenergy production through:

- Additional jobs at regionally distributed slow-pyrolysis units.
- New business opportunities for biochar sale and distribution.

Specifically for Queensland, the degraded soils used for sugar cane farming would benefit the most from biochar addition. Burning of sugarcane trash can be replaced by pyrolysis and production of biochar that is then added to soils.

11.10 Competition

In the long-term, biochar and bioenergy production need to be assessed concurrently due to their common use of biomass as feedstock. Currently, there is not enough available biomass and combustion units to satisfy future C and bioenergy markets. Competition between the energy sector (bio-ethanol production) and biochar production should be avoided and instead adequate assessments need to be made how to best optimise the available feedstocks for biochar and bioenergy production. These optimisations will be different according to the regions. It is noteworthy that bioenergy requires specific feedstocks whereas biochar can be made of almost any biological waste material that is free of toxins.

11.11 Biochar case study

Australia has over 545,000 ha devoted to sugar cane production. The area of sugarcane production in Queensland has increased by over 40% since 1988 and now exceeds 508,000 ha and cane fields represent 20% of Queensland's total crop area. Most cane is grown within 80 km of the coast, mainly in high rainfall areas and along numerous river systems. The size of Queensland cane farms varies from 30 to 120 ha and the average cane farm produces 5840 tonnes of sugarcane.

Usage for biochar

In the lower Burdekin alone, about 8 million tonnes of sugarcane are produced annually. Of this amount, at least 960,000 tonnes (or 12%) are cane trash that would be directly available for biochar production (Figure 11-5). In addition to the cane trash, some bagasse from the mill production could be available. Currently, the majority of the trash is burnt pre-harvest but burning is slowly being phased out. Thus, a major issue facing the industry is the managing of the large amount of trash left behind.

Some areas have developed effective green cane trash blanket farming techniques. However, due to farm layouts and infrastructure limitations, much of the region will not be able to farm effectively with green cane. If it can be proven to be profitable, biochar appears to be a good solution to these issues.

Real life example:

Sugar cane farmer Jim Southern, a local grower and advocate of biochar, estimates that his Grower Group of Airdmillan could produce 50,000 tonnes of cane trash biomass each year. His fields are optimised for collection and transport to a nearby plant and then redistributed back to his fields. Conversion of cane trash (not including bagasse) would result in 12840 tonnes of biochar annually (25%), which could be spread to his soils or sold to other interested parties. Possible application rates of biochar can vary from 1 to 30 t ha⁻¹. While there is currently no knowledge about a safe upper limit, Lehmann *et al.* (2006) noted that an application of 50 t ha⁻¹ should not be exceeded.

Assuming that total area of his Group is 50ha with an application rate of 20 t ha⁻¹ would result in a sequestration of 1000 tonnes of sequestered C.

Note that these calculations do not take into account the avoided emissions from manufacture of fertiliser (if there is decreased fertiliser used based on better nutrient use efficiency), change in soil C due to any avoided N₂O and CH₄ emissions from agriculture and landfills.

The methodology table (Table 11-2) provides a summary of the potential for avoided CO₂-e through the use of sugar cane trash and bagasse for Queensland and nationally.

The estimate for use of sugarcane waste for biochar production yields 0.26 CO₂-e per tonne feedstock. This is based on a conversion rate of 33% and a 70% C content of biochar. These estimates are comparable with the use of greenwaste material (35% conversion rate and 75% C content of biochar), yielding 0.23 CO₂-e per tonne feedstock.

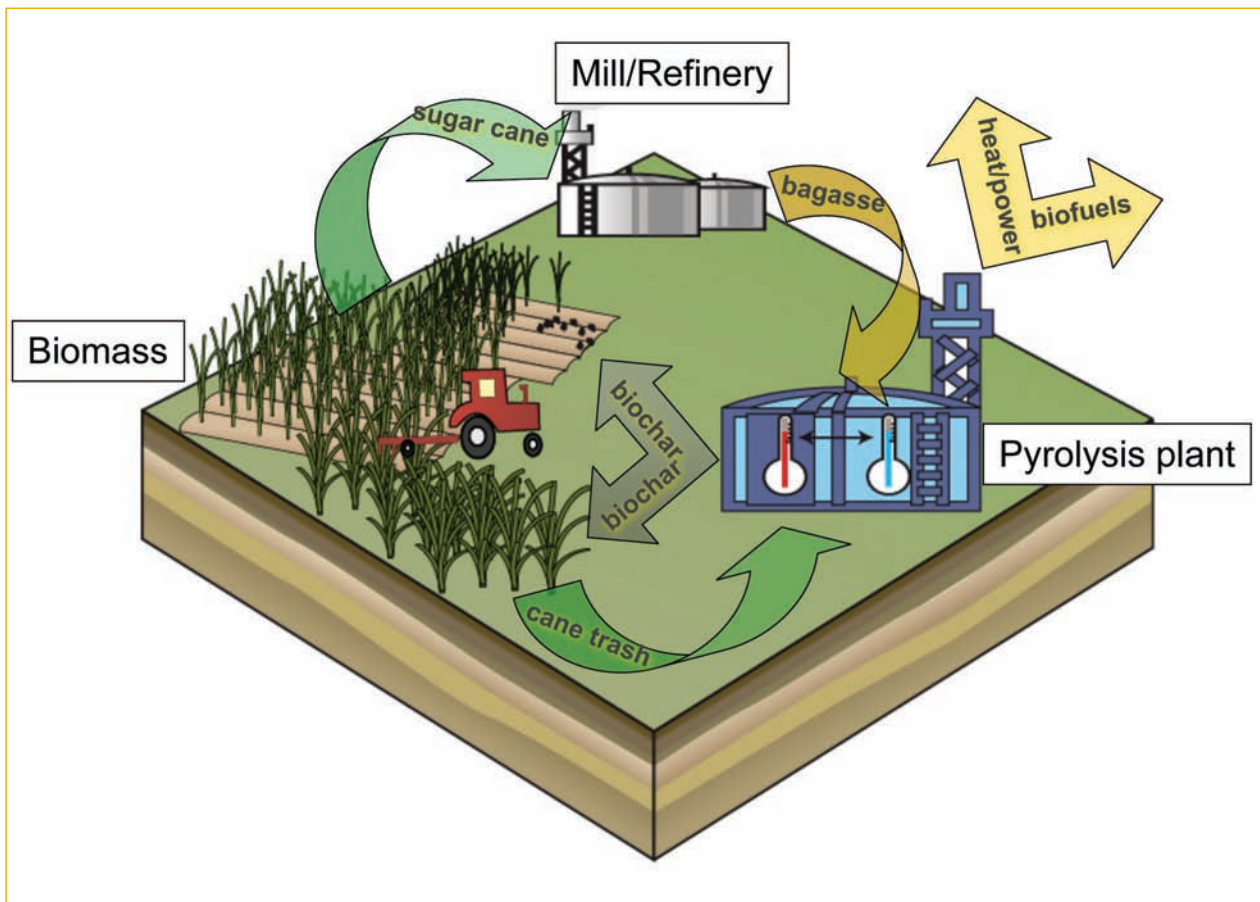


Figure 11-5: Illustration of the application of sugar cane trash and bagasse conversion to biochar. Note that the transport ways between field, refinery and pyrolysis plant should be kept to a minimum to avoid unnecessary fossil fuel emissions.

In summary there is much potential for biochar production and usage in Queensland. Proper life cycle assessments need to be established to ensure that transport and production costs and associated greenhouse gas emissions are kept to a minimum. The optimum pathways in which bagasse could be used to simultaneously maximise profit, minimise GHG emissions or sequester C, or replace fossil fuels will need to be investigated in more detail. Studies that determine the specific effects of biochar from certain materials (e.g. sugar cane waste) to certain soils need to be conducted first before biochar usage can be recommended at a specific rate.

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11.13 Research Groups

National

- NSW Department of Primary Industries
- CSIRO Land and Water
- Department of Agriculture and Food
- Richmond Landcare

Universities

- University of NSW
- University of Adelaide
- University of Western Australia

International

- Massey University (New Zealand)
- Landcare Research (NZ)
- Cornell University (USA),
- Edinburgh University (UK),
- The University of Newcastle (UK)
- University of Zurich (Switzerland)

11.14 Research Activity and Focus

Most research projects are mainly focused on describing results of field or laboratory pot trials rather than investigating the underlying processes that caused the observed effects. There is little scope for comparison between these studies as different biochar products are used on different soils with different crops, under different climatic regimes and with different application rates and fertiliser amendments. Few studies have engaged in detailed analyses of the causes of fertility increases after biochar application, the different mean turnover times of different biochar products or characterisation of biochars through NMR, nanoSIMS, NEXAFS or TEM/SEM analyses. While initial research results show that biochar application to soil can increase crop productivity (and as such increase biomass production, which in turn temporarily sequesters C), it is currently not possible to extrapolate these results to all soil or crop types or climate regimes of Australia.

Importantly, research results from studies done in the northern hemisphere cannot be assumed to produce similar results under Australian conditions due to the very different climatic and pedological conditions. Studies determining the exact C sequestration potential of biochar are very sparse due to the need for longer term investment to study the short, medium and long-term dynamics of biochar stability in soil and changes in stocks of other soil carbon fractions.

While it is well known that biochar has a greater stability compared with the biomass that it is produced from, current estimates vary from less than a hundred to thousands of years. In terms of credible C accounting, indications are that the stability of biochar, produced at or above 400 degrees C from a source such as wood cuttings or stubble residue should result in sequestration over a timeframe that is relevant to the 100 year timescale of Australia's CPRS.

More data are necessary, however, to adequately quantify the potential reduction in other greenhouse gases (e.g. CH₄ and N₂O), the role of biochar in production enhancement, native organic matter stabilisation or destabilisation avoided emissions from landfill. Finally, only limited risk assessment for the safe use of biochar and appropriate application rates, life-cycle analysis and economic assessment have been initiated.

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Additional information and links:

Australia biochar network <http://www.anzbiochar.org/index.html>

Biochar, climate change and soil: A review to guide future research. CSIRO Land and Water Science Report: 05/09. 64 pp. This report summarises the major findings and outstanding research issues on biochar, climate change and soil. (64 pages) <http://www.csiro.au/resources/Biochar-climate-change-and-soil.html>

Biochar Factsheet <http://www.csiro.au/resources/Biochar-Factsheet.html>

Biochar for environmental management, Science and Technology, edited by Johannes Lehmann and Stephen Joseph, Earth scan publishers (see http://www.earthscan.co.uk/Portals/0/pdfs/Biochar_Press_Release.pdf)

International Biochar Initiative <http://www.biochar-international.org/>

11.15.1 Appendix A: International context and carbon accounting

Several countries (28 to date) have endorsed the use of biochar as a climate mitigation and C sequestration tool through a submission to the UNFCCC. For example, the Federated States of Micronesia (FSM) has filed a submission to the United Nations Framework Convention on Climate Change (UNFCCC) to introduce biochar as a technology for consideration as a 'fast-start' strategy to mitigate climate change. The submission includes biochar on the draft agenda to be considered during the UNFCCC negotiations in Copenhagen in 2009. This is significant as it officially positions biochar as a mitigation technology prior to the post-2012 framework.

The submission by FSM follows the filing of a submission by the United Nations Convention to Combat Desertification (UNCCD) endorsing biochar. The UNCCD, a sister convention of the UNFCCC, identified biochar as a unique opportunity to address soils as a C sink. This is in line with its 10-year strategic program that calls for the promotion of low-C footprint sustainable practices and technologies.

According to the Intergovernmental Panel on Climate Change (IPCC), biochar management would be a valid C sink in the current and post-2012 "Land Use, Land-Use Change and Forestry" (LULUCF) guidelines.

The mitigation benefits of biochar can be accounted for in several ways. Firstly, the renewable energy output would be counted as a reduction in greenhouse gas (GHG) emissions from the energy sector in national level emissions accounting. At the project scale, if implemented outside a capped sector, it could generate a credit for avoided GHG emissions, calculated from the displacement of fossil fuel energy. Recognition of reduced fossil fuel use, such as resulting from increased use of renewable energy, is a common feature of mandatory and voluntary emissions trading schemes (ETS).

Credit could also be claimed for avoided emissions from a change in the management of biomass, where the conventional management leads to emissions of CH₄ or N₂O. Several schemes recognize the benefit of avoided CH₄ emissions where waste is diverted from landfill (e.g., by NSW GGAS), or management of manure is improved (e.g., by RGGI).

Increase in soil C stock through biochar application could be recognized as an eligible sequestration activity. Theoretically it could be claimed under Kyoto Protocol Articles 3.3, 6 (J1) and 12 (CDM), if applied to forest, or Article 3.4 if applied to agricultural land. However, modification of the standard methodology of estimating soil C (IPCC, 2006) would be required. Due to concerns about permanence and additionality, sequestration projects are often subject to strict criteria governing eligibility, estimation and reporting, which can escalate transaction costs and restrict participation. Difficulties in accurate monitoring of soil C due to spatial and temporal variation have been raised as barriers to inclusion of agricultural soil management in emissions trading. The VCS, for example, proposes a method requiring monitoring that involves sampling to prove the permanence of C stored in soil over time (VCS, 2007). However, in contrast, the CCX has successfully monetized soil C sequestration using conservative defaults to estimate sequestration based on implementation of eligible management practices rather than monitoring soil C change (CCX, 2007b). Estimating soil C change due to biochar application could be based on an estimate of the quantity of C applied and the turnover rate, which should be much less uncertain than estimating impacts of tillage or grazing practices on soil C (Ogle *et al.* 2003).

An alternative approach could be taken to claiming credit for C captured and stored in biochar: rather than focusing on the increase in soil C stock, credit could be based on the avoided C emissions due to stabilizing organic matter. However, this approach would not readily fit within the offset rules of schemes currently operating, as most schemes do not recognize avoidance of CO₂ from biomass decomposition. One possible exception is the California Climate Action Registry (www.climateregistry.org), which recognizes ongoing storage of C in wood products. Under this scheme a claim for credit for ongoing storage of C in biochar as a component of the wood products pool may be accepted (this has not been tested, and would be applicable only where biochar is created from wood obtained from eligible forests).

The reduction in agricultural emissions resulting from application of biochar to agricultural land is also tradable. Under Article 3.4 of the Kyoto Protocol, increased sequestration in plants and soil resulting from biochar-induced enhancement of productivity could be credited.

In conclusion, assessment of the various schemes indicates that pyrolysis of biomass for bioenergy and biochar could be claimed through various routes: credit for bioenergy is widely recognized; credit for increasing C stocks in the soil, if biochar is applied to an eligible forest, is recognized by several schemes; avoided landfill emissions, and avoided emissions from manure could be claimed under a few schemes; one scheme recognizes agricultural management of soil C, and one recognizes long-term storage in wood products, either of which could provide an avenue to crediting the benefit of pyrolysis in stabilizing organic matter.

Table 11-2: Methodology for estimating potential, attainable and base greenhouse gas sequestration/mitigation for biochar**.

Option	Stabilisation of organic carbon in soil through biochar production Bioenergy credit for displacing conventional electricity	
Current or Business as Usual Net Carbon Storage (Mt CO₂-e) from 2010 to 2050	0	
Net Potential* Carbon Storage (Mt CO₂-e) from 2010 to 2050	Australia	8.6 Mt/yr Scaled up to 342.94 Mt for 40 year period.
	Queensland	7.8 Mt/yr Scaled up to 309.9 Mt for 40 year period. Bioenergy 2.34 Mt/yr 94.31 Mt for 40 years
Functional Unit and Basic Algorithm Used to Calculate per Unit CO₂-e	Tonnes of sugar cane. Total sugarcane production (QLD and Australia-wide) is assumed to remain constant; 36 Mt cane nationally, with 2.5 Mt cane grown in states other than Qld. Biomass available for biochar production was assumed to be 80% of trash and 50% of bagasse. Under specified pyrolysis conditions to maximise char production the yield of biochar and carbon content was estimated. Mitigation potential of cogeneration of bioenergy during pyrolysis was based on CO ₂ emissions from conventional Qld electricity generation that could be avoided.	
Scaling Up Process	Scaling up the per annum figures was done assuming constant production of biomass over the 40 year period. Biochar potential that uses all available feedstock (biowaste, green waste, manure etc) has not been estimated. The figures presented are based on one case study (unpublished data) and are therefore not necessarily representative for whole of Queensland or whole of Australia; yet, they provide a valuable guide to the possible scale of sequestration/ mitigation for a major waste resource in Qld.	
Attainable* Net Carbon Storage (Mt CO₂-e) and factors driving this translation	Queensland	3.9 Mt/yr 154.95 Mt for 40 year period Bioenergy 1.17 Mt/yr 47.16 Mt for 40 years The attainability depends on the implementation of pyrolysis plants and adoption by the sugarcane industry. A good estimate for what is attainable is probably half of what is maximum physically possible (net potential) for biochar.
Base* Net Carbon Storage (Mt CO₂-e) and factors driving this translation	Reaching the boundaries of sensible estimation, therefore, base not estimated. Depends on the economics and price of C as well as the degree of public acceptance and adoption of biochar technology. Implementation also depends on a proper risk assessment study with regard to what the maximum amount of C can be stored in soil without reducing fertility. Such studies do not require large, long-term investments but can be carried out in conjunction with farmers and as short-term lab and greenhouse studies.	

* See Chapter 1 Section 1.2 Methodology for explanation of potential, attainable and base.

** Estimates are based on one case scenario for use of sugar cane waste materials, expanded for the whole of Queensland (the major sugar cane producing state within Australia: 508,000 ha) and for all of Australia (>545,000 ha). This example was chosen due to waste materials from sugar cane production being readily available and therefore biochar appears to be a good solution to the issues of excess waste management (e.g. via burning) in association with usage of uncharred waste materials (e.g. compost). Other examples for future CO₂-e reduction would be the use of waste from tea-tree farming for biochar production, in association with C storage in soil. Soil nutrient/structure benefits of biochar (avoided N₂O) are not estimated.

12 Incentives for biodiversity plantings: multiple values from carbon markets

Scott Heckbert and Andrew Reeson

12.1 Definition and Scope

Inclusion of reforestation in Australia's Carbon Pollution Reduction Scheme will have implications for natural resource management. On one hand carbon forestry could improve water quality, erosion control, biodiversity, salinity, and if managed well at a landscape scale could enhance resilience of natural assets under a changing climate. Conversely, if incentives for these multiple benefits are not recognised, poorly coordinated plantings at a landscape scale could negatively impact biodiversity and water availability, and an opportunity to capture benefits of forests beyond carbon and timber may be lost. To correct this issue, a number of policy arrangements could be used such as funding institutions like the proposed National Carbon Bank (Wentworth Group 2008). This paper identifies issues relating to reforestation, capturing multiple benefits, and contributing to natural resource management goals. Biodiversity plantings in Queensland are discussed, with four criteria identified for successful realisation of multiple benefits from such plantings, namely biophysical potential for greenhouse gas (GHG) sequestration, economic viability, institutional support, and adoption of activities.

12.2 Introduction

Many environmental problems arise because ecosystem services such as regulating atmospheric temperature, provision of biodiversity, clean air and clean water are not valued in markets. Markets are a means of social coordination, and well functioning markets can efficiently allocate scarce resources among competing users, promote innovation, and achieve efficient outcomes at least cost. Hence the role for carbon markets to efficiently distribute limited rights to produce greenhouse gasses (GHG). All markets require some degree of regulation. Property rights must be defined and enforced, and be legally transferable between traders. Information must be available for market participants to make informed decisions, and a means provided for them to locate and interact with each other. Social impacts and spill-overs into other areas, termed 'externalities', must be considered. These externalities can result in public values being adversely impacted through private actions, as is considered here for the case of carbon markets and carbon forestry in Queensland.

The creation of a regulated market for carbon is a step toward correcting a major market externality. Carbon markets place a value on the sequestration of carbon or abatement of GHG emissions. The price of carbon, however, does not place direct value on other ecosystem services that are associated with carbon sequestration. A market for carbon, with a price only for the change in carbon sequestration could involve perverse outcomes for other ecosystem services. There is the potential for carbon markets to generate a new set of environmental negative externalities. For example, carbon markets may promote planting monocultures of fast growing tree species, which may not be ideal for local biodiversity and downstream water availability. Land use change may convert agricultural land to forest with losses of food and fibre, with flow on effects elsewhere in the economy. The configuration of land use change offers an opportunity for non-market benefits such as improved biodiversity, water quality, and water availability management, and this opportunity may be foregone if incentives at the property-scale do not reflect overall public values.

Dollars and carbon have historically been separated in our economy, the former a production value, and the latter an externality. Placing a price on carbon removes this dichotomy of production and carbon, making them comparable so tradeoffs can be made between them. However, carbon then becomes separated from other non-priced goods to which it is physically related, namely biodiversity. In essence, the externality is passed on to biodiversity, and we can expect adverse impacts to occur as the carbon market follows the relevant price signals to this effect.

A number of mechanisms exist which can assist in ensuring values for carbon do not exclude values for other non-market benefits. Market-based instruments (MBIs) have been widely used in Australia for managing natural resource management (NRM) goals including biodiversity, and can be designed to accompany the proposed Carbon Pollution Reduction Scheme (CPRS) to avoid perverse outcomes. We discuss important considerations associated with designing market mechanisms that are realistic, acceptable, feasible and offer maximum benefits with minimum impacts. The following sections identify criteria to achieving this outcome, comprising four considerations for the implementation of successful greenhouse gas abatement or sequestration activities:

- Biophysical limits determined by carbon yield and emissions estimates for various management practices
- Economic considerations determined by cost of abatement, and considering benefits from markets and also non-market values

- Institutional settings determined by policy and governance arrangements
- Social context influencing adoption of land uses and management practices, determined by landholder decision making.

The current science frontier is mainly focussed on the former two issues of biophysical and economic research, and as these become clearer, the design of institutional frameworks, and how adoption might occur can be addressed.

Market-based instruments are an example of an institutional arrangement to offer landholders/land managers a balance of incentives that reflects the overall public values that we wish to achieve. In the case of the CPRS, supporting institutions and regulatory tools can be used to assist in balancing the appropriate incentives. An example is the proposed National Carbon Bank, as outlined by the Wentworth Group of Concerned Scientists (2008), which outlines an incentive system to achieve multiple ecosystem services values from reforestation.

In short, the proposed National Carbon Bank (NCB) involves using carbon forestry projects to contribute to national greenhouse gas emission targets, and also restore native vegetation, notably along Australia's river systems thereby improving water quality and securing landscape health in the face of climate change (Wentworth Group 2008). This submission to the Garnaut Review asserts that funds generated from targeted biodiversity plantings, or otherwise earmarked from the sale of permits in the CPRS, could be made available to projects who contribute to multiple benefits. Catchment management authorities could prioritise project areas and certify management plans in accordance with local NRM priorities, which would in turn be eligible for NCB funding. The proposal suggests prioritising projects initially by restoring native vegetation along rivers, wetlands and estuaries; second to expand habitat to create viable populations of threatened species and ecological communities; thirdly terrestrial storage of carbon in agricultural landscapes.

The scale of potential carbon forestry activities in Queensland is enormous, and uptake of agro-forestry practices will depend on the incentives faced by landholders. Concern has been raised related to whether tree species best suited for fast carbon sequestration are best suited for biodiversity and water issues. However, if values for biodiversity and other ecosystem services can be incorporated alongside the carbon price, there is great potential for carbon markets to contribute to improving natural assets, and contributing natural resource management objectives in Australia.

12.3 Biophysical potential

Polglase *et al.* (2008) present 10 agro-forestry possibilities, one of which is 'environmental plantings'. This agro-forestry activity presents an ideal example of GHG mitigation which can provide multiple environmental benefits. In Chapter 9 of this report, Polglase reports that 10 Mha of environmental plantings would be economically viable in Queensland at \$20/t CO₂-e. The total annual rate of carbon sequestration is 56 Mt CO₂-e/yr for this area. The study finds that environmental plantings could expand into lower rainfall zones of 400-700mm/yr. The spatial distribution is depicted in Figure 12-1 and summarised in Table 12-1.

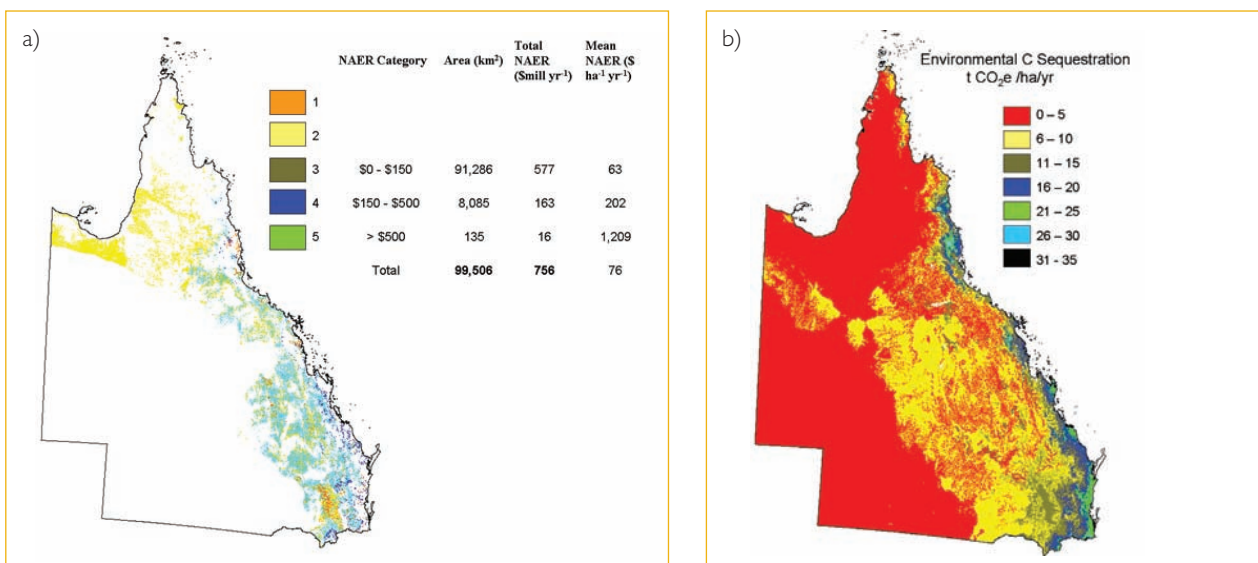


Figure 12-1: a) Economically viable areas (Net Annual Equivalent Return >\$0) for environmental plantings at a carbon price of \$20/t CO₂-e, including opportunity costs of agricultural land. Classes 1 and 2 are negative NAER values. b) Predicted rates of CO₂ sequestration in live biomass (above- and below-ground) for environmental plantings.

Table 12-1: Potential, attainable and base sequestration rates from environmental plantings in Queensland, under conservative assumptions.

Net Potential* Carbon Storage (t CO ₂ -e) from 2010 to 2050		Functional Unit and Basic Algorithm Used to Calculate per Unit CO ₂ -e	Scaling up	Attainable* Net Carbon Storage (t CO ₂ -e) and factors driving this translation	Base* Net Carbon Storage (t CO ₂ -e) and factors driving this translation
Australia	Queensland	Assume an average rate of carbon sequestration of 5.6 t CO₂-e ha-1yr-1 for carbon plantings over 40 years. The value includes a 30% discount as a 'risk buffer' for disturbances.	The average rate of sequestration over 40 years (5.6 t CO₂-e ha-1yr-1) is multiplied by the area of land planted (and the number of years) There may be additional emission reductions from displacing livestock and other agricultural use.	Queensland 1,120 Mt CO₂-e 28 Mt/yr Assume that 50% of the total available land is planted.	Queensland 112 Mt CO₂-e 3 Mt/yr Assume that 10% of each available farm is reforested.
14,000 Mt CO₂-e.	2,240 Mt CO₂-e 56 Mt/yr Assuming a carbon price of \$20 t-1 CO ₂ , the area of economically viable environmental reforestation is 10 Mha. Values are higher for higher carbon prices.				
350 Mt/yr Includes a 30% discount for a 'risk buffer'.					

* See Chapter 1 Section 1.2 Methodology for explanation of potential, attainable and base.

The magnitude of carbon forestry opportunities in Queensland is large; the question being what type of forest mosaic might be created under different incentives. Fensham and Guymer (2009) estimate that woody regrowth as Kyoto-compliant reforestation on cleared land amounts to an area of 14.8 Mha in Queensland. What land managers will inevitably decide to use for various forms of production depends in part on the relative economic values, namely the carbon price. The amount of land which is planted/ reforested in Australia will depend on this price. ABARE (2008) reports 2.78 Mha will be converted to environmental plantings under conservative scenarios, and 21.9 Mha under higher carbon prices.

12.4 Economic Values

Discussion on the uptake of GHG mitigation activities, and the choice between creating environmental plantings or other agro-forestry options, rests to a large degree on the price for carbon that will be realised under the CPRS. This price signal informs tradeoffs between different production systems and management practices. Concern has been raised whether tree species best suited for fast carbon sequestration may have adverse impacts on biodiversity (e.g. Hunt 2008).

Treasury modelling for estimating the price of carbon under the CPRS is presented in *Australia's Low Pollution Future*.

The Economics of Climate Change Mitigation. The report concludes that Australia's emission price will be determined by global market prices. Higher prices are required to realise lower GHG stabilisation levels. Stabilisation at 550 ppm CO₂ represents the Government's current commitment to reduce GHG emissions by 5% (CPRS - 5), and is estimated to require a price of \$23/t CO₂-e in 2010. To achieve a 15% reduction (CPRS - 15), stabilisation rests at 510 ppm, with a requiring a price of \$32.2/t CO₂-e. To achieve 450 ppm (scenario beyond the proposed 5-15% reduction) would require a price of \$48.3/t CO₂-e.

Economic values for carbon forestry include timber and carbon in market-defined dollar values, and values not represented by dollars, such as the environmental services which benefit society and are not traded in markets. Environmental economics identifies a taxonomy of human values for environmental services, from consumptive production values (e.g. eating cultivated food) which are represented by prices in markets, across the spectrum to non-market values which may be less tangible (e.g. the 'option value' of simply knowing an endangered species exist, although you may never see one personally). Environmental valuation is the practice of quantifying these, as discussed in Adamowicz (2004). Tradeoffs can be assessed through valuation, and requires ecosystem services to be commensurable (people are willing and able to forego their benefit to gain utility elsewhere).

A non-monetary approach to the same issue is measuring contributions to 'human wellbeing'. The Millennium Ecosystem Assessment (MEA 2005) outlines the contributions of environmental services to human wellbeing. In the case of a carbon forestry project, this framework would classify benefits of; supporting services (such as nutrient cycling), provisioning services (timber), regulating services (water purification), and cultural services (aesthetic, recreational). Cultural values are important for Indigenous Australians for whom non-timber products from native forests and woodlands, such as bush food and medicines, are typically of equal or greater interest (Heckbert *et al.* 2008).

Biodiversity values in carbon forestry activities are important for a number of reasons. Their primary goal is to provide habitat for a variety of species but also environmental plantings are likely to prove more resilient to climate change, fires, pests, weeds and water scarcity. Biodiversity and ecosystem service values are not covered in the Kyoto Protocol and are generally absent from carbon markets aside from the need to perform an environmental impact assessment, and mitigate loss of biodiversity as a result of the project under the Clean Development Mechanism (PROBASE 2003).

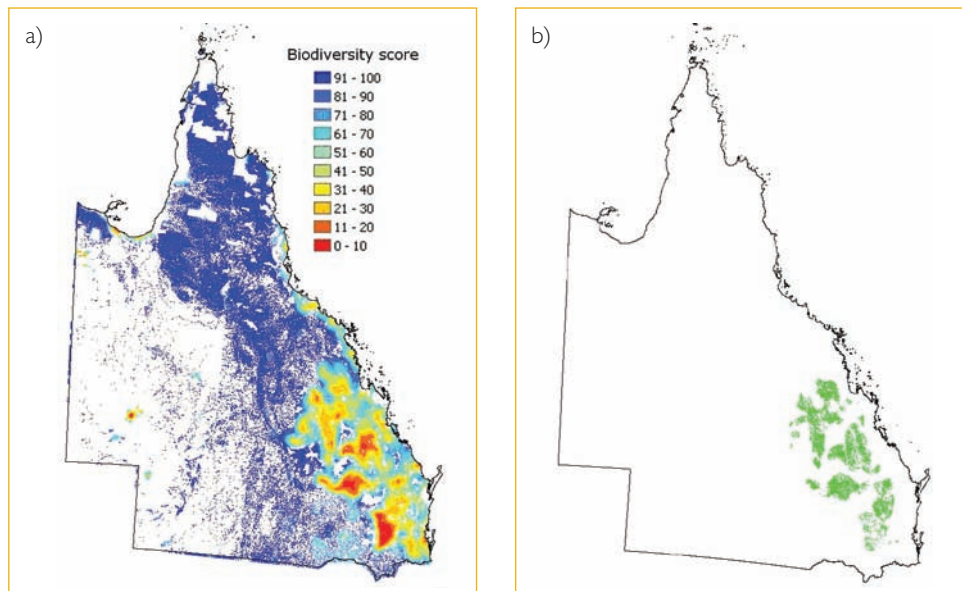


Figure 12-2: Based on Polglase et al. (2008), a) Biodiversity score related to fragmentation of native vegetation. Low score indicates need for reforestation, and b) Map of all areas for environmental plantings that meet the multiple criteria of being profitable, intercept least amount of water compared to grassland, and biodiversity need is greatest (NAER > \$0, water interception < 150 mm/yr and biodiversity score < 50 units).

A key step to quantifying biodiversity values is an ability to measure these for a given project/location. A number of biodiversity metrics are noted as possible options to inform the relative values of locations, namely Gibbons et al. (2009), Parkes et al. (2003), and Freudenberg and Harvey (2003). In Polglase et al. (2008) a GIS metric is calculated based on the patchiness of remnant stands, and proximity to native vegetation, calculating a conservation value for areas, as depicted in Figure 12-2.

12.5 Institutional Conditions

The discipline of institutional economics deals with social based ways of coordinating exchanges, including regulatory constructs and markets for the efficient allocation of resources. The CPRS is a statutory market, which will inevitably exist alongside other forms of institutions such as environmental regulations administered by government bodies and statutory authorities, as well as non-statutory (voluntary) markets for carbon, biodiversity, and other environmental services and social outcomes. It is likely that a mix of institutions, both statutory and otherwise, will emerge to address the issue of GHG mitigation from a holistic perspective. We can expect some mix of voluntary markets and other institutions to exist alongside the CPRS.

A good analogy is that of Medicare in Australia, and we use this example as a comparison to the CPRS. Medicare covers essential health care services, those that are deemed basic medical necessities, those which have a firm scientific basis and provide the greatest health outcomes at the least public cost. However, that does not preclude the existence of other medical institutions such as private R&D firms, NGOs as service providers, and private health care schemes. For example, cutting-edge cancer research is an important element of a holistic health care industry, but a private individual wanting to support such research would not make a donation to Medicare, rather there are non-statutory institutions which conduct such activities. A cancer treatment that was once experimental and has developed a firm scientific basis might make its way from an R&D arm of a university, through a number of 'strata' of health care institutions, eventually to be covered under Medicare once uncertainties are diminished, risks known, and the need for such treatments are apparent and cost effective to the public.

Extending the analogy back to the CPRS, in a similar vein we might expect land use activities with a high degree of scientific certainty, such as carbon forestry activities, to appropriately be covered initially by the CPRS. There are hundreds of years of scientific understanding about tree growth and landscape management by foresters with empirically validated estimation models, and therefore a firm understanding of how forestry can assist with GHG mitigation. However, other GHG mitigation options

such as savanna burning or soil sequestration might have higher uncertainty, unclear property rights, and less depth of knowledge within the field of science. That is not to say savanna burning and soil sequestration are not important activities which can assist in GHG mitigation, merely that some might not be suitable for initial inclusion in the CPRS. These options might be better placed under voluntary market or other MBIs specifically designed to accommodate activities with certain risk and uncertainty profiles. Hence these activities might start outside of the statutory CPRS, but eventually make their way into the scheme as information and acceptance of their value becomes well established (or not).

The CPRS White Paper is explicit in the limits of the scheme's scope:

The Scheme regulator will not have the capacity to assess the natural resource management implications (for water or biodiversity) of reforestation activities. For this reason, and to ensure that multiple regulators do not make decisions on the same issues, the Government will not require the Scheme regulator to take account of natural resource management issues when assessing whether forests should receive permits. The existence of separate frameworks for natural resource management complements such an approach. (pg 6-49)

GHG mitigation through land management necessarily involves spatial and temporal considerations. MBIs or a voluntary market could be managed by appropriate NRM bodies to provide incentives suited to their location. Such an MBI might best be nested within the already existing NRM institutional structures that exist in Australia, such as catchment management authorities (CMAs), other regional NRM bodies or statutory authorities, or a combination of government bodies. These bodies could act as a conduit for certification of GHG mitigation activities, and perhaps act as carbon pool managers for their region.

Uncertainty surrounding coverage of agriculture in the CPRS can impact on elements of the institutional setting, namely confidence of investors and landholders, particularly as a new market and lack of knowledge is a barrier to entry. Certainty about the core CPRS will assist in allowing the institutional setting to emerge, and to include strata of statutory markets, designed MBIs, and voluntary markets.

We suggest that integrated modelling of biophysical and institutional economics can determine the MBI design to provide cost-effective GHG mitigation, while protecting and enhancing other ecosystem services and offering flexibility to landholders. Examples of such modelling include landowner response to financial incentives for biodiversity (Nelson 2008), as well as modelling MBIs (Heckbert 2009), and more broadly institutional design (Whitten *et al.* 2007, 2008).

While carbon trading offers an efficient method of meeting national emission targets, a number of issues need to be navigated properly. Measuring and monitoring GHG emissions and defining additionality of emissions reductions is challenging for agriculture and forestry. Additionality and permanence of carbon sequestration are hard to define and enforce. In voluntary markets experience has shown it is very difficult for buyers to check that carbon they are buying is actually being provided (e.g. Murray and Dey 2009). Unlike other markets, individual buyers never actually consume the product – they are buying compliance permits (in the case of regulatory markets) or “warm glow” or reputation (in the case of voluntary markets).

Examples such as the NCB are useful for guiding incentives for GHG mitigation projects, and could harness the benefits of markets to allocate funds to achieve multiple benefits. NCB could be large enough to manage risks of carbon sequestration, and have both the ability and the will to replace losses of sequestered carbon. The challenge is to design institutions which would enable an instrument to operate as efficiently and effectively as possible, maximising its impact on both carbon and the broader environment.

12.6 Adoption

Adoption of land use GHG abatement activities is the final step once the biophysical, economic, and institutional conditions are present to support such projects. Adoption arises due to a myriad of reasons that are specific to the individual decision maker involved, and go beyond dollar values that are associated with a project. As discussed earlier, there are many forms of non-market economic values which may be more important in many cases, based on the preferences of the individual. Beyond even these less tangible values, human decision making is complex. Many examples can be drawn from associated research on adoption of land management practices.

Adoption of management practices and changed land uses can be seen as a dynamic learning process. Adoption depends on a range of personal, social, cultural and economic factors, as well as the ability to trial the practice, and have it deliver ‘relative advantage’. Adoption occurs when landholders perceive that it will enhance the achievement of personal goal, including economic, social and environmental goals Pannell *et al.* (2006).

According to this understanding, information for learning, experience by trials and exchange of information by extension is likely to support adoption in this new area of carbon values. Cultural ties, identity, relationship to land and how management practices enhance or detract from held values will influence behaviours based on preferences for/against activities.

12.7 Conclusions

In summary, the successful uptake of GHG mitigation activities will depend on biophysical, economic, institutional, and adoption considerations. For the most part, the biophysical elements of GHG mitigation are either known or at least knowable within the existing scientific understanding of carbon cycling and land management. From this biophysical base economic estimates and modelling can inform the tradeoffs between market and non-market values, again a research area that is fairly well understood. However, the institutional and adoption elements are less well represented in the current conversations surrounding the design of the CPRS. In summary, these four elements must be considered:

1) Biophysical conditions

- Carbon sequestration rates, yield curves over time, and emissions regimes
- The effect of a land management practice on GHG cycling

2) Economics of land management

- Estimates of project and property viability, costs, benefits, liabilities, from perspective of altered financial incentives of multiple land use options
- Estimates of non-market values and impacts on other NRM goals such as biodiversity and water quality and availability, and impacts on livelihoods
- Mitigation project as business diversification, with tradeoffs both at property and regional scale

3) Institutions:

Policy conditions

- Coverage of CPRS
- Specifically designed market-based instruments for environmental regulation, used in combination with other typical ways to encourage best management practice, such as incentives to adopt, through education, moral suasion, financial incentives (tax and subsidies), MBIs.
- Payment for environmental services (PES): biodiversity and social licence to operate under CPRS, voluntary markets and negotiated agreements

Market design

- Barriers such as transaction costs of monitoring, regulation, enforcement, market engagement, information finding, access to credit for start-up costs, verifying changes in stocks or emissions
- Property rights under various legislation, definitions of transferability and point of obligation (farm or factory)
- Market design (coverage, banking) and transition to CPRS (stages to CPRS inclusion in 2015), and access to voluntary markets

Governance arrangements

- Arrangement/network of organisations providing assistance and encouraging participation, from community to government agencies and others.
- Engagement models of community-based, regional NRM body, multi-stakeholder to best suit adoption
- Role of CMAs, regional NRM bodies, and organisations such as NAILSMA, GBRMPA and QLD EPA.

4) Adoption of mitigation activity

- Information for learning, experience by trials and exchange of information by extension
- Suitability under local decision making processes, community capacity to engage, customary arrangements which influence decision making
- Cultural ties, identity, and relationship to land
- Project development initiatives involving developing management plans, extension, trials, financial support for adoption, skills and training
- Behaviours related to external drivers such as market structure and preferences for/against activities

12.8 Contributors

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Appendix A: Authors and contributors

Short Working Title

- Regrowth
- Livestock
- Soil Carbon
- Rangelands
- Mulga
- Savanna
- Plantations
- Pre-1990 Eucalypts
- Carbon Forestry
- Biofuel
- Biochar
- Biodiversity

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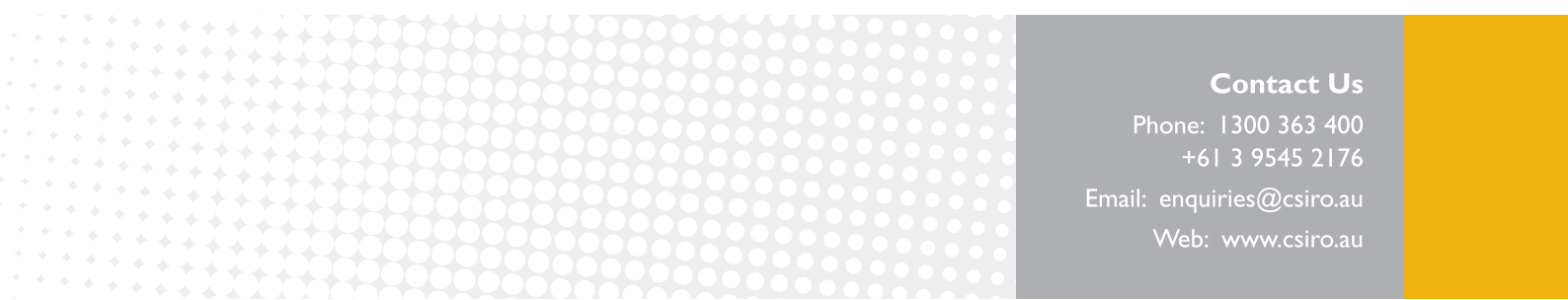
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