CLIMATE CHANGE AND THE AUSTRALIAN AGRICULTURAL AND LAND USE INDUSTRIES*

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Biological processes turned a sulphuric and carbonic atmosphere that was incompatible with animal life into an oxygen rich atmosphere that we can breathe. At the same time, they changed the earth's climate, with greenhouse effects bringing temperatures within the ranges that support human civilization as we have known it over the past dozen millennia.

Algae and plants converted sunlight and carbon dioxide from the atmosphere into organic compounds that were held in living plants or buried in the earth's crust, and oxygen that was released into the atmosphere.

Human activity since the dawn of modern economic development in the late eighteenth century, and especially as modern economic growth has become established in the heartlands of the most populous developing countries in the early twenty first century, has partially reversed this atmospheric change. The amount of carbon stored in plants and soils has been reduced, and some of the carbon stored in fossil fuels has been returned to the atmosphere through combustion and use in industrial processes.

Biological processes can play major roles in mitigating the effects of human activity on climate. Algae and plants have a track record. They have done it all before, on a much larger scale than is now required.

There is currently a surreal discussion in Australia of climate change, agriculture and land use. Leaders of farm industry groups and political leaders with claims of representing farm communities are vocal in their criticism of efforts to reduce Australian greenhouse gas emissions. Last week in the Northern Territory I heard reports of pastoral interests talking about the proposed Australian Emissions Trading Scheme "decimating" some farming activities in Australia. And yet there is little comment from these same interests on the high risks to Australian farming and rural communities of unmitigated climate change.

"Decimation" was the disciplinary practice of Roman Generals, of having every tenth soldier kill the man adjacent to him as punishment for some widespread error, such as the looting that followed Caesar's conquest of Spain. The careful modelling conducted within the Garnaut Climate Change Review suggests that there is little likelihood of decimation of Australian farm production from Australia playing its full proportionate part in an ambitious global mitigation effort. Unfortunately, the mainstream science tells us that decimation - destruction of one tenth - would be a wildly over-optimistic expectation for Australian farm production with unmitigated climate change. In some major parts of Australian farm activity - for instance irrigation farming in the Murray Darling basin - we may not see one tenth of output survive a comprehensive failure of global mitigation.

My own work during the Review, and the work of others since, suggests that Australian rural communities not only have overwhelmingly strong interests in effective climate change mitigation, but also have potential for gains from climate change mitigation. In Australia more than any other developed country, and more than almost all developing countries, comprehensive emissions accounting and the systematic reward of carbon sequestration could add significantly to rural incomes. But much work has to be done before there is systematic reward of reduced emissions and increased sequestration from agriculture, forestry and land use.

Chapter 22 of the Garnaut Climate Change Review discussed the interrelationships of climate change and its mitigation with agriculture, forestry and land use. It looked speculatively at some future possibilities that have been given an unreasonably small place in Australian and international discussions of mitigation. It sought to draw attention to the large potential for low-cost emissions reduction and bio-sequestration in the Australian rural sector. It aimed mainly to create interest in and to encourage further work on these apparently rich opportunities.

Ideas discussed in Chapter 22 of the Review have been taken up in policy statements by the Leader and the Environment Shadow Minister of the Federal Opposition. They have been the subject of important new work by the Queensland Government with the CSIRO, and by many specialist groups, including the North Australia Indigenous Land and Sea Management Alliance. The Australian and other Governments have been promoting the more widespread acceptance of bio-sequestration opportunities in the emerging international greenhouse gas mitigation regime. Australia is a bit closer to defining the potential contribution of mitigation to Australian rural communities and of rural communities than it was a year ago.

This evening I will go over some of the ground covered in Chapter 22, and conclude with an assessment of how things look nine months after the presentation of the Review to Governments.

Some key points

Effective mitigation would greatly improve the prospects for Australian agriculture Choices for landowners will include production of conventional commodities, soil carbon, bioenergy, second-generation biofuels, wood or carbon plantations, and conservation forests. The realisation of this potential requires comprehensive emissions accounting. The realisation of a substantial part of the biosequestration potential of rural Australia would greatly reduce the costs of mitigation in Australia. It would favourably transform the economic prospects of large parts of remote rural Australia.

Full utilisation of biosequestration could play a significant role in the global mitigation effort. Outside Australia, it is of powerful significance for Australia's immediate neighbours, Indonesia, Papua New Guinea and the other countries of Southeast Asia and the South Pacific. Getting the incentive structures right at home and abroad to realise the enormous potential for biosequestration is a major challenge, and potentially Australia's most important contribution to the global mitigation effort.

Climate change and climate change mitigation will bring about major structural change in the agriculture, forestry and other land use sectors. With effective global action, climate change mitigation would become the more important force for change. A rising carbon price will alter the cost of land management practices and commodities, depending on their emissions profiles. On the other hand, without mitigation, and in the next few decades in any case, projected temperature increases and decreased rainfall are likely greatly to reduce agricultural and pastoral potential in traditional Australian agricultural regions. This will particularly affect industries that rely on irrigation and those that are currently operating near the margins of profitable cultivation. In the longer term, land managers will respond to these dual challenges by pursuing new opportunities in carbon removal (or sequestration), energy production from biomass and low-emissions livestock production. Such opportunities could significantly lower the economy-wide cost of the emissions trading scheme - far below those suggested in the Review's modelling of the costs of mitigation.

Agriculture and forestry will experience the effects of climate change differently, and their prospects for adaptation and emissions mitigation also differ. While these sectors warrant separate consideration, they are inextricably linked. Both provide products and services based on natural systems. The issues they face can be relevant to a single landowner or business.

Drivers of a transformation towards lower emissions In Australia, emissions mitigation has been pursued for several years, particularly in the forestry sector, as many existing mitigation policies and agreements recognize and provide credit for carbon removal by forests. Land clearing has slowed significantly since 1990, primarily due to regulatory controls. Forests and plantations established after 1990 accounted for net removal of about 23 Mt CO2-e in 2006, and are the reason that Australia has lived within its emissions allocations under the Kyoto Protocol.

Mitigation through forest sinks has been encouraged by demand for emissions reduction certificates or offset credits under a number of domestic programs. At the same time, there has been increasing interest in a range of low- to negative-cost emissions reduction activities in the agriculture sector, which generally also provide productivity benefits, such as fertiliser management. It is important that an emissions trading scheme with comprehensive coverage replaces and expands incentives for mitigation in the agriculture and forestry sectors. For activities not included in the scheme, other policies will be required to drive mitigation unless and until land use emissions were incorporated comprehensively within an emissions trading scheme.

An emissions trading scheme

When it is introduced by the Commonwealth Government, an emissions trading scheme (ETS) will be the primary instrument driving emissions mitigation in Australia.

In relation to the treatment of forestry and agriculture under an emissions trading scheme, the Review proposed the following approach:

• Those undertaking reforestation should be allowed to opt in for coverage (that is, liability for emissions and credit for net removal from the atmosphere) from scheme commencement.

• Those undertaking deforestation should be liable for resulting emissions.

• There should be full coverage of the agriculture, forestry and other land use sector, based on full carbon accounting once issues regarding emissions measurement, estimation and administration are resolved.

• Policies should apply to the agriculture sector to drive mitigation until it is covered under the scheme.

The over-riding idea should be one of providing incentives for net sequestration within a comprehensive carbon accounting framework.

Full coverage of the agriculture, forestry and other land use sector would involve accounting for all greenhouse gas emissions and removal on managed land, including soil carbon, forests and wooded lands (regardless of the date of establishment) and life-cycle emissions from, and carbon storage by, harvested wood products. The 2006 IPCC Inventory Guidelines provide a useful framework for the development of a comprehensive approach to accounting. However, emissions reported do not necessarily have to align exactly with emissions liabilities or credits under an emissions trading scheme.

Economic modelling results: a possible future?

The Review's modelling considered possible outcomes for Australia's economy without mitigation, and also considered the impacts of an emissions trading scheme under three technology assumptions: 'standard', 'backstop' and 'enhanced'. The focus was on the transition for the agriculture and forestry sectors in Australia in a world with effective global action on mitigating emissions (stabilisation at 550 ppm CO2-e or 450 ppm CO2-e under standard technology assumptions). It did not take into account some of the main opportunities for biosequestration discussed in this paper. It reflected continuing application of current Kyoto Protocol rules as adopted by Australia - including Australia's decision so far not to opt in to the more expansive coverage of Article 3.4 of the Kyoto Protocol, and relevant clauses of the Marrakesh Accords.

With the 550 standard technology scenario, non-combustion emissions from all three sources are lower than under the no-mitigation scenario; however, agricultural emissions still increase slowly to around 30 per cent above 2005 levels by mid-century, before declining to 5 per cent above 2005 levels in 2100. By 2100, in the 550 standard technology scenario, the agriculture sector is responsible for more than 41 per cent of total Australian emissions and is by far the largest source of emissions.

The modeling within the Review suggested that the carbon price would be about $40 per tonne of carbon dioxide equivalent in 2013 under an ambitious (450ppm) global objective, and about $25 per tonne with a more limited (550ppm) global concentrations objective. In each case the price would rise at a rate that would roughly double the price in real terms every 20 years. As the carbon price increases, it creates incentives to reduce more and more agricultural emissions further.

The rate of emissions intensity reduction in the agricultural sector in the first half of the 21st century under the 550 standard technology scenario reflects the limited mitigation options available at the prevailing carbon price.

After 2050, the higher carbon price leads to emissions reductions that would require a widespread change in agricultural practices and/or consumer tastes, or the implementation of new technologies. By 2100, output from the sector is almost four times larger than in 2005, but agricultural emissions are just above 2005 levels and emissions intensity levels have decreased by more than half relative to current levels.

A scenario was run through the model assuming emissions reductions from forestry activities were not eligible under the global emissions trading scheme. To achieve the same level of mitigation without forestry activities, the carbon price is consistently 30 per cent higher than when forestry activities are included and when standard technology assumptions are used. The higher carbon price leads to higher gross world product costs. In Australia, GNP in 2100 is half a percentage point lower in 2100 when forestry is not included, compared to the same mitigation scenario where it is included. This sensitivity illustrates the potential impact of excluding forestry activities from emissions accounting. It also demonstrates how the availability of large, low cost sources of mitigation can reduce the global costs of mitigation policy. Such sources could include soil carbon or biochar, or a new technology to reduce emissions from livestock.

After 2050 the benefits of mitigation (avoided climate change) start to become evident when the 550 standard technology scenario is compared to the no mitigation scenario. With unmitigated climate change, all agricultural subsectors experience a reduction in output by the end of the century as temperatures increase and water availability decreases as a result of climate change. Water-intensive or water-dependent industries such as grain, farm dairy and horticulture are particularly affected.

Under the 550 standard technology scenario, a large proportion of climate change impacts are avoided. Those sectors that benefit more from the avoided impacts of climate change, and are affected less by rising carbon prices, show higher levels of output in 2100 than in the no-mitigation scenario.

The forestry sector, which includes environmental plantings, is stimulated by the introduction of an emissions trading scheme. Demand for offset credits (from carbon removals) increases demand for forestry output, which include logging and services associated with plantations, in the 550 standard technology scenario. The forestry sector increases by more than 20 times by 2100 and its share of overall activity more than doubles relative to 2005 levels.

While activity in the agriculture sector increases by 2100, agriculture has a falling share of total output. The composition of the agriculture sector changes: output from sheep and cattle, grains and dairy decreases relative to the no mitigation scenario, while the share of other animal products and other agriculture, including horticulture, increases.

The sheep and cattle industries are highly emissions intensive, and there are currently limited opportunities for the reduction of methane emissions. Other meat products, such as pork and chicken, are less emissions intensive. While the model allows for substitution between existing meat products in response to the carbon price, there is no explicit consideration of alternative sources of animal protein that are not currently widely consumed, such as kangaroo meat.

In response to a carbon price on the agricultural sector, households move away from meat and meat products because of the higher price of these commodities under an emissions trading scheme. Households also move away from beef and lamb towards less emissions-intensive meat, such as chicken and pork. A similar pattern of change is observed in Australia’s export of meat and meat products under the mitigation scenarios.

While the share of output in the sheep and cattle industries is reduced in comparison to the no-mitigation scenario, real production in the 550 standard technology scenario still increases by around 150 per cent from current levels by 2100.

Modelling land use, land-use change and forestry emissions is complex and difficult, and the results should be seen as a guide only to the possible implications of the forestry sector's response to a carbon price.

The forestry sector responds to the carbon price by establishing new plantations. In the modelling, three types of forestry activity were assumed to be available - softwood and hardwood timber plantations and environmental (carbon sequestration) plantations. All types have establishment costs, but carbon plantings do not have transport or harvesting costs.

The forestry modelling took in land currently used for all forestry and agricultural activities, including minimally adjusted pastures used for livestock production in remote areas of Australia. The extent of new land dedicated to forestry is determined by the value of forestry activities compared to the value of agricultural activities competing for the land.

Forestry experiences a significant change between the no-mitigation and effective global mitigation scenarios. Under the no-mitigation scenario, emissions from forestry rise over the study period, to the point where it is a net source of emissions in some years. By contrast, under the 550 standard technology scenario forestry is consistently an emissions sink, with removal from the atmosphere increasing particularly after the late 2020s, and reaching almost 60 Mt CO_2-e in 2050.

The fluctuations in forestry emissions are due to assumptions regarding harvesting periods for timber plantations and the maturing of environmental plantations. Carbon plantations are assumed to reach maturity after 45 years, after which no further carbon removal occurs. After 2050 in the 550 standard technology scenario, net sequestration from forestry activities declines and approaches zero by 2100.

After 2050, few new plantations are established due to rising land prices and competition with higher-value agricultural uses. By the end of the century, just over half of the new land under forestry is dedicated to carbon plantings.

Far more land goes to forest sinks in the 450 standard technology scenario; this reflects the higher carbon price. In the 450 scenario, higher carbon prices are reached earlier in the century when land values are lower, so that forestry activities, especially carbon plantations, are more competitive.

In the Review's modelling, land use and land-use change emissions – for instance, a liability for landowners for emissions from clearance, or the opportunity costs of reduced clearance - were not included. Rather, land use and land-use change emissions are imposed in the models. Land use emissions for

Australia largely represent emissions from clearing of regrowth as part of agricultural management - rather than clearing for new land. In the no-mitigation scenario, emissions from land clearing were assumed to remain at 44 Mt CO2-e per year throughout the modelling period, based on a simple extrapolation from projections in the most recent national emission projections (DCC 2008c). Under the modeled policy scenarios, clearing emissions are assumed to decline in a linear fashion in response to the carbon price, to 28 Mt CO2-e by 2050 and reaching zero by 2100.

The modelling exercise assumed that the emissions intensity of fuels such as petrol and diesel would decrease over time through an increase in the share of biofuels. However, the potential impacts of increased domestic demand for first-generation biofuels is not reflected in competition between different uses of land. Due to the difficulty in making predictions about second-generation biofuel technologies and costs, the modelling did not include any progress in these technologies under a carbon price. If domestic production of bioenergy were to increase, there could be greater competition for land that is currently assigned in the model to food or forestry production.

An alternative future

There are major opportunities to reduce emissions and increase greenhouse gas removal in the agriculture, forestry and other land use sectors. Few of these are incorporated in the modelling results. Some combination of them could reduce radically the cost of mitigation in Australia and transform the economic prospects of rural Australia, especially of remote areas. Options include reducing emissions from major sources (sheep and cattle), and carbon dioxide removal in forests, other types of vegetation and soil. Producing biomass as a feedstock for biofuels and other forms of energy could also reduce emissions. These biosequestration activities appear to offer the largest emissions reduction potential.

These sectors could reduce emissions and exposure to an emissions price through other means too - improved management of manure, changed methods of rice cultivation and reduced fuel and electricity consumption are all promising options. However, because these options are likely to offer relatively small emissions reduction benefits, they were not considered.

Estimates of some technical potential for emissions reduction and removal in the agriculture, forestry and other land use sector were summarised in Table 22.2 and Box 22.2 of the Review. It was recognised that these potentials were calculated in a context of uncertainty and that their realization would require substantial investments in proving and developing the systems. Further, since some of the identified processes overlap, their mitigation potential is not intended to be aggregated. Rather, they were listed to provide a broad sense of the

mitigation possibility if policy, program and research efforts were more heavily focused on
endeavours that recognised the integration of climate change mitigation with the management of agriculture, forests and other land use issues.

Methane emissions from cattle and sheep

In Australia, enteric fermentation emissions from livestock (mainly sheep and cattle) account for about 67 per cent of agricultural emissions (DCC 2008b). Cattle and sheep production also accounts for a significant proportion of emissions from agricultural soils, and beef production is responsible for some emissions from savanna fire and land clearing.

Over time, increasing permit prices will encourage reduced use of energy and emissions-intensive inputs and drive mitigation of livestock emissions. Current options for the mitigation of methane emissions include:

• Practices to increase productivity - selective breeding, better location of watering points and greater use of products that promote growth can all increase productivity without increasing food consumption and resultant emissions (Eckhard 2008; Howden & Reyenga 1999).

• Nutritional management - The addition of monesin, dietary fats and lipids can reduce ruminant emissions by 20 to 40 per cent (Beauchemin et al. 2008; Howden & Reyenga 1999). Nitrous oxide emissions from livestock can also be reduced through dietary changes (Miller et al. 2001; van Groenigen et al. 2005). These options are technically feasible, but would require a substantial emissions price to be commercially interesting.

• Vaccination, biocontrols and chemical inhibitors - Trials of immunization on sheep found methane emissions reductions of almost 8 per cent (Wright et al. 2004). This is a longer-term category - it may be decades before this is feasible on a large scale.

To the extent that there were no cost-effective mitigation options, the purchase of permits would lead to an increase in costs of sheep and cattle production. In the short to medium term, the impact on meat prices and consumption may not be large as permit prices will be a relatively small component of the cost of animal products. The competitive position of Australian producers may improve relative to those in cold winter countries of the northern hemisphere. These changes would take place against a backdrop of rising global demand with incomes growth in the successful developing countries.

Over time, consumption patterns in Australian households are highly responsive to changes both in price and conditions of supply. As permit prices increase, higher prices for some meats are likely to lead to further changes in consumption patterns.

Sheep and cattle production is highly vulnerable to the biophysical impacts of climate change, such as water scarcity. This factor, combined with increased costs for methane emissions, could hasten a transition toward greater production and consumption of lower-emissions forms of meat, such as chicken, fish and pork. Demand for these products is projected to remain strong. Australian marsupials emit negligible amounts of methane from enteric fermentation (Klieve & Ouwerkerk 2007). This could be a source of international comparative advantage for Australia in livestock production. For most of Australia's human history - around 60 000 years - kangaroo was the main source of meat. It could again become important. However, there are some significant barriers to this change, including livestock and farm management issues, consumer resistance and the gradual nature of change in food tastes.

Soil and emissions

Atmospheric carbon dioxide is removed from the atmosphere by plants and transferred to soil through active plant roots or the decomposition of plant and animal matter.

Soil carbon is both a source and a sink of greenhouse gases. Soil carbon can be restored and increased through active management of the biological system. It can be affected by employing conservation tillage; increasing the use of mulch, compost and manure; and changing the vegetation cover on soil. Soil carbon can be built with the use of further soil additives, including calcium-bearing silicates (Engineering and Physical Sciences Research Council 2008) and biochar (see section 22.3.4). Tests are now being conducted using lignite as a catalyst for accumulation of soil carbon (LawrieCo 2008).

Soil carbon can be lost—for example, as a result of land clearing, erosion or drought (Lal 2004). Soil carbon built up by conventional cropping with reduced tillage (such as 'zero-till' methods) may only affect soil close to the surface, and is often returned to the atmosphere within months (J. Baldock 2008, pers. comm.; Lal 2004; Chan unpublished). By contrast, carbon dioxide removed by actively growing roots of living plants and stored in soil humus can provide long term storage. Increased soil microbe activity associated with increased vegetation is essential for soil carbon sequestration. This promotes plant availability of soil minerals and other nutrients, improves soil structure and humus content, increases water retention and increases oxygen respiration to the atmosphere (Jones 2008; Parr & Sullivan 2005; Post & Kwon 2000).

There are other benefits from building soil carbon. It increases oxygen and retention of moisture when combined with other nutrients and minerals, leading to improved soil health (Grace et al. 2004; Jones 2007; Lal 2007; Wentworth Group of Concerned Scientists 2008). As a result, a number of Australian land managers are already making on-farm changes to build soil carbon (Jones et al. 2008). Australia is well positioned to further increase carbon dioxide removal by soil, due to the sheer size of its land mass and the ability of its farming sector to adopt new management practices.

A range of biophysical, economic and social constraints must be overcome in order for the sequestration potential of carbon in soils to be realised on a large scale, although it is already technically feasible.

The barriers to recognising carbon dioxide removal by soil could be overcome within decades, presenting soil carbon as a new commodity for landowners.
Though the potential is not as great as in high-quality soil, removal by soil may offer an alternative to other forms of biosequestration in areas of low rainfall or scarce water supply.

Nitrous oxide emissions that result from soil management can be reduced through currently feasible activities—fertiliser management, soil and water management, and fertiliser additives (de Klein & Eckhard 2008). These mitigation activities can significantly reduce costs. Organic additives are low-emissions alternatives to conventional fertiliser that are already available. Further research and development may help to identify new biological products that are appropriate for fertilizer production, and could also improve the efficiency of chemical fertilisers (Hargrove 2008).

Building soil carbon may have implications for nitrous oxide and other emissions, for example increases that may arise from chemical fertilisers (Changsheng et al. 2005; Grace et al. 2004).

Forests

The profitability of harvested forestry systems can be improved if carbon is included as an additional, saleable product. Analysis by Polglase et al. (2008) concludes that carbon payments could increase the profitability of hardwood and softwood sawlog systems, but not of pulpwood. Carbon revenue has a lower impact upon pulpwood production because rotation periods are relatively short and these systems have less opportunity to store carbon compared with longer rotation sawlog systems.

There will be significant financial opportunities for landholders who intend to maintain permanent forest cover. However, participation in the carbon market will also carry risks, especially for landholders who intend to change from forestry to another land use and, to a lesser degree, for those who intend to harvest their forests. Permits or credits generated as a growing forest removes carbon dioxide from the atmosphere will need to be surrendered when the forest is harvested. There is scope to reduce the carbon liability incurred when trees are harvested if inventories, and the emissions trading scheme, recognise carbon stored in harvested wood products. The provisions of the Kyoto Protocol do not account for carbon in harvested wood products. However, the 2006 IPCC Inventory Guidelines provide detailed guidance on how to estimate the contribution of harvested wood products to emissions and removals. The approach requires estimation of emissions from the decay of all wood products in the 'products in use' pool and would be likely to result in an increase in Australia's reported greenhouse gas emissions (G. Richards 2008, pers. comm.).

There are flaws in the approach. This is an important issue that warrants further analysis and then international discussion. The objective should be to credit genuine, multiyear sequestration of carbon in harvested wood products. A large switch in land use toward production forestry would have additional consequences that might be negative (such as impacts on water supply) or positive (for example, mitigating dryland salinity and assisting with habitat restoration), depending on the type of forestry and the land use it replaces. These externalities should be addressed through the creation of market-based instruments for other ecosystem services, such as water quantity and quality, biodiversity, air filtration, and batement of salinity and erosion.

Biofuels

Subsidies and mandated targets for biofuels distort the market. The correct way to support mitigation through biofuels involves placing a price on all greenhouse gases arising from the production process and the combustion of the biofuel. This is achieved through including inputs into and the use of biofuels comprehensively in the emissions trading scheme.

Global production of biofuels in 2005 amounted to roughly 1 per cent of total road transport fuel consumption (Doornbosch & Steenblik 2007). Satisfying the global demand for liquid fuels with current (first-generation) biofuel technologies would require about three-quarters of the world's agricultural land (Oxburgh 2008). First-generation biofuels can therefore never amount to more than a minor supplement. In the future, second-generation biofuels, using resources that are not applied to food production, will be valuable.

Biofuels can be produced using second-generation technologies from waste biomass, lignocellulosic materials or algae. Australian native trees offer a wide range of possibilities. Mallee eucalypts, for example, can be grown on marginal arid and semi-arid lands, including land that seems to be in the process of conversion out of wheat growing by the warming and drying of southeast Australia. The mallee green top can be harvested perennially as a biofuel feedstock. The growing of mallee can lessen dryland salinity and assist in habitat restoration without competing directly with fibre production from the forestry sector. Mallee also contributes directly to mitigation through storage of carbon in its massive root system.

Biofuel production using algae can be concentrated in terms of land use. Its essential requirement is energy from sunshine. Algae can absorb carbon dioxide from the atmosphere and thrive on concentrations of the gas from combustion wastes. They do particularly well in saline environments, which are abundant in Australia and have no alternative commercial uses.

Trials of the production of second-generation biofuels are already proceeding, although there are as yet no full-scale production facilities in operation. It could qualify for commercialisation support under the innovation proposals of Chapter 18, and will be encouraged by a rising carbon price. Commercial production of second-generation biofuels could reasonably be anticipated before 2020 Biomass can be converted to other forms of energy, such as heat and electricity. Biomass could be the basis for ‘negative emissions’ energy if it is coupled with carbon capture and storage or secure storage of biochar. While biomass offers the only promising way of making clean liquid fuels for vehicles, there are other ways of generating electricity cleanly, so that biofuel is likely to be the early target of commercialisation (Oxburgh 2008).

Polglase et al. (2008) assessed the potential economic outcomes and environmental impacts across Australia of agroforestry for dedicated bioenergy and integrated tree processing (that is, integrated production of bioenergy, activated carbon and eucalyptus oil), based on various species of mallee and other eucalypts. They conclude that dedicated bioenergy and integrated tree processing systems are unlikely to be profitable unless they are close to processing facilities. This is due to the high cost of production (harvesting and transport) relative to the low product price for wood energy. Lehmann (2007) suggests that, in the United States, biochar production in conjunction with bioenergy from pyrolysis could become economically attractive at an emissions permit price above US$37 per tonne.

Woodlands conservation

Australia has large areas of land which would be suitable for carbon plantings and revegetation.

There are about 28.8 ha of forest and wooded land for every person in Australia (FAO 2008). This is the largest area of forest and wooded land per person among OECD countries and the second largest globally.

In addition to land area, the amount of additional carbon dioxide that can be removed from the atmosphere by existing forests and woodlands and through revegetation of cleared lands is determined by the local climate, the fertility of the substrate, the characteristics of the plant species and the impact of land use history in reducing carbon stocks below the land's carrying capacity.

Polglase et al. (2008) have undertaken extensive analysis of the opportunities for carbon farming across Australia, taking account of climatic and soil suitability, species characteristics, the likely profitability of carbon farming compared with current land use and the potential impact on rainfall interception and biodiversity benefits. They modelled environmental plantings of mixed species with an open woodland structure, as well as monocultures of eucalypts and pines. Taking account of climatic and soil suitability, they find that there is about 200 million ha of land suitable for carbon plantings with potential revenue of up to $40 billion per year. This does not suggest that all land will be planted. That will depend on land availability, social attitudes, investment and farming models, and intersection with other policy (for example, on water and planning).

Opportunities for profitable carbon farming have no harvesting or transportation costs and location is not constrained by proximity to processing facilities. Moreover, the carbon payment can be an annuity and financial returns are not delayed by years or decades until trees are harvested.

As provisions for carbon accounting become more comprehensive, carbon dioxide removal from the atmosphere could be a substantial new source of revenue for managers of national parks and forests set aside for conservation. However participation in carbon markets would also entail risks. Liability for emissions arising from fires would be the most significant risk, and would require management responses. Some but not most forests are already close to their carbon carrying capacity.

The IPCC default values for temperate forests are a carbon stock of 217 tonnes carbon per ha and net primary productivity of 7 tonnes of carbon per ha per year (IPCC 2000). However these IPCC estimates may be conservative, particularly for intact forests. Mackey et al. (2008) have shown that the stock of carbon for intact natural forests in south-eastern Australia is about 640 tonnes per ha, with an average net primary productivity of 12 tonnes per ha per year. They estimate that the eucalypt forests of south-eastern Australia could remove about 136 Mt CO2-e per year (on average) for the next 100 years.

About a quarter of Australia is covered by savanna woodlands and grasslands, and much of this land is owned and managed by Indigenous Australians (Tropical Savanna Cooperative Research Centre 2008). The upgrading of savanna management has substantial mitigation potential, and would also have positive effects for biodiversity conservation and for Indigenous land managers. Under its implementation of the Kyoto Protocol, Australia can only account for carbon dioxide removed on land that was cleared at 1 January 1990, and most savanna areas do not satisfy this provision. Future carbon accounting provisions should include all greenhouse gases removed by and emitted from managed lands.

This would provide significant revenue opportunities for land managers. It would also require the management of risks, especially if liability for emissions resulting from non-anthropogenic activities - such as fire and the effects of drought - were brought to account.

Savanna fires are the principal source of greenhouse gas emissions in the Northern Territory, and a significant source of Australia's agricultural emissions. Ignitions of savanna fires are frequently anthropogenic (Russell-Smith *et al*. 2004).

Reducing savanna fires can significantly increase biosequestration and protect carbon stored in vegetation sinks. Actions to reduce the area burnt include seasonally targeted management strategies such as fire breaks, early and seasonal burning, and fuel reduction burns. The West Arnhem Land Fire Abatement project provides a working model which is the subject of current Australian and international scientific analysis (Tropical Savanna Cooperative Research Centre 2008; Whitehead *et al*. in press).

Barriers and limits to a low-emissions future

More reliable and cost-effective ways to measure or estimate net emissions are needed in the land use sector. Without reliable estimation, it is difficult to include the sector in an emissions trading scheme.

Estimation of emissions and removal by soils is particularly difficult. There are models - such as the Rothamsted soil carbon (RothC) and GRC-3 (DCC 2008a) - but actual samples often provide different results. Soil carbon is characterised by spatial, seasonal and annual variation. Sampling is intensive and costly, and data are limited. Emissions estimation is also difficult for nitrous oxide and native forests.

Resources should be directed, as a priority over the next few years, to overcoming gaps in emissions data and measurement issues for the agriculture, forestry and other land use sectors, in order to include all of the sector's emissions in accounting and potentially in an emissions trading scheme. In addition, training will be needed to ensure that Australia has the skills needed for monitoring and verification.

The same issues arise in relation to Australia's developing country neighbours. Australia has been helpful in sharing knowledge of carbon measurement techniques in Papua New Guinea, Indonesia and elsewhere. Extending this work can be a large Australian contribution to the global mitigation effort.

If emissions removal processes are not recognised in accounting protocols, they cannot assist in meeting emissions obligations - which reduces the incentive to pursue them.

Accounting and coverage by an emissions trading system should be as broad as possible in the land use sector. This would minimise the likelihood of perverse incentives. With incomplete coverage (for example, exclusion of emissions from deforestation), a carbon price could provide a financial incentive to clear land for biosequestration or bioenergy even though this could result in a net increase in emissions.

The accounting framework for Australia's emissions under the Kyoto Protocol is not comprehensive. The dampening effect this has on the take-up of biosequestration was evident in the Review's modelling results, which assumed continuation of existing emissions accounting rules. As new global emissions accounting methods are developed, alternative technologies and forms of biosequestration should be considered. Australia should advocate movement towards comprehensive monitoring, reporting and recognition of emissions from land use.

It is also important that Australia take full advantage of whatever international accounting rules are in place. The Marrakesh Accords (UNFCCC 2002) of the Kyoto Protocol determined that any Annex I party (such as Australia), in addition to claiming emission reductions from afforestation, reforestation and deforestation (under Article 3.3 of the Protocol), could (under Article 3.4 of the Protocol)

> *'choose to account for anthropogenic greenhouse gas emissions by sources and removals by sinks … resulting from … revegetation, forest management, cropland management, and grazing land management'.*

Australia has opted not to account for emissions in these areas. While there are valid concerns about the impact of bushfires on emissions, and these need to be addressed, it is in Australia's interests to implement as wide-ranging a definition of human-induced greenhouse gas emissions as possible.

It will be important to account for all emissions - including those caused by natural processes - although it may not be appropriate to include all emissions in an emissions trading scheme. Clear rules will be needed about how non-anthropogenic emissions, such as those caused by drought and fire, might be managed. The potential contribution of biosequestration, much of it at relatively low cost, to the mitigation task is immense. This is true for the world, and particularly true for Australia. Comprehensive emissions accounting as a basis for the emissions trading scheme's application to agriculture, forestry and related sectors could meet a major part of Australia’s mitigation effort. The exclusion of comprehensive accounting from the modelling of the Review’s costs of mitigation is a large source of conservatism in the estimates of the costs of mitigation in Australia.

There are promising research avenues for reductions in agricultural emissions. Large-scale, and widely shared, public good research in this area is warranted.

The transaction costs of full inclusion of agriculture in an emissions trading scheme would be high. There are around 130 000 agricultural establishments in Australia (ABS 2007), each with a diverse emissions profile. Inclusion of agriculture in an emissions trading scheme will involve a trade-off between accuracy and cost. Both will be significantly influenced by the threshold set for coverage and the point of obligation. There will be a large role for collective action among farmers, or private broking functions, to reduce the costs of individual farmers’ interaction with an emissions trading scheme.

Concluding thoughts

There has been much discussion of the contents of Chapter 22 of the Review within Australia and overseas. As is the way with these things, there has been some trivialization of the issues - BBC television wanted to interview me about the effects of increased kangaroo meat consumption on the traditional British roast beef Sunday lunch. But there has also been much serious research into the issues. Some of this will receive attention in the near future with the release of work by the CSIRO commissioned by the state government on the mitigation potential of land use change in Queensland.

Over the past year, it has become clearer than ever that early large progress on reduction of emissions will require major contributions from the biological processes. It has also become clear that the achievement of ambitious goals on eventual concentrations of greenhouse gases in the atmosphere - 450 ppm and better - will involve overshooting, and the use of technologies that actually remove greenhouse gases from the atmosphere. Here the biological processes are the proven technologies and have major roles to play.

Effective use of the biological opportunities for reducing and sequestering emissions requires large commitments for public funding on research, development and commercialization of new variations on old technologies, and on measurement of emissions changes. Australia has a proportionately larger national interest in this work than any other countries. And yet our commitments to research in this area have been miniscule compared, for example, to our commitments in geo-sequestration of emissions from coal combustion (carbon capture and storage CCS).

There is a strong case for a large Australian effort on the CCS technologies. There is at least as strong a case in the national interest for a large effort on the biosequestration opportunities.

The Garnaut Climate Change Review suggested that we should do both, and more, with funding from the sale of emissions permits under the ETS. Under current proposals, the potential revenue from the ETS is largely spoken for, as compensation to households and free permits to industry.

It will not be easy to find large public financial resources for research development and commercialization of new technologies of any kind in the difficult budgetary circumstances that now stretch out into the future as far as we can see. This makes it critically important that free permits to trade-exposed industries are withdrawn immediately as the case for them - potential carbon leakage - is removed by other countries' adoption of carbon constraints.