GHG Balance of bioenergy systems based on Integrated plantation forestry in North East New South Wales, Australia

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Abstract

Australia is heavily reliant on fossil fuels, particularly coal, for electricity production, but is now encouraging expansion of renewable energy to reduce greenhouse gas (GHG) emissions. Plantation forests are a potential source of biomass for renewable bioenergy. This study examines the potential GHG emission reduction from bioenergy utilising thinning, harvest and sawmill residues from plantation forests in northern NSW. Using a life cycle assessment (LCA) approach, two alternative energy conversion options were compared: co-firing in black coal power plants located distant from the plantation region, or in stand-alone wood-fired plants located within the plantation region. Emission reduction per ha, and per unit electricity produced were calculated for two levels of plantation productivity. The potential emission reduction from forestry in Northern NSW was estimated using published predictions of future expansion of plantations in this region.

Co-firing gave higher emissions reduction per ha, and per unit of biomass, due to the greater efficiency of energy conversion by co-firing. However, co-firing gave lower emissions reduction per MWh, compared with the wood-fired option, due to the greater fossil fuel input required for transport. The emission reduction benefits of the wood-fired plants would increase, and possibly surpass the co-fired option, if high efficiency IGCC technology was employed.

The potential biomass production from 180 000 ha plantations in northern NSW was estimated to be 2.03Mt dry matter per annum. The potential power output was estimated at 3090 GWh_e per annum from co-firing, or 2120 GWh_e pa for the wood-fired option, giving net GHG emission reduction of 2.63 Mt CO_2e and 1.93 Mt CO_2e per annum for the co-fired and wood-fired alternatives, respectively.

Introduction

Australia is heavily reliant on coal for electricity production, and biomass accounts for around 0.5% of the electricity supply (ABARE 2007). New policy measures to reduce emissions of greenhouse gases are stimulating interest in renewable fuels: federal legislation has set a target of increasing renewable energy by 9 500 GWh/a by 2010, and in the state of New South Wales, mandatory emission reduction targets have been imposed on electricity retailers. Hence, amongst other renewable energy sources, bioenergy systems are being investigated. Options under consideration include utilisation of forestry residues, either by co-firing in existing coal-fired power stations, or through the development of new wood-fired power stations in forestry regions. These two alternatives for utilisation of forestry residues differ in efficiency of thermal conversion, plant construction requirements and transport distances.

The area of eucalypt plantations is expanding in Australia, and these may potentially provide a biomass resource for bioenergy. In NSW the majority of eucalypt plantations are sawlog species, intended to meet future timber demand as harvest of native forests is phased out. Under current practices, residues from thinning are left on the forest floor to decay, residues from harvest of sawlogs are windrowed and burned in the forest, and mill residues are often burned to waste. Potentially, each of these three residue resources could be utilised for bioenergy.

Expansion of plantations is being promoted to provide diversified income and employment to rural communities, and environmental benefits from carbon sequestration, enhanced biodiversity and, in inland areas, management of dryland salinity. The area of plantations in northern NSW is about 70 000ha (Wood et al, 2001). A study of future plantation expansion by the Australian Bureau of Agricultural and Resource Economics and Bureau of Rural Sciences (ABARE/BRS 2001) predicted the future plantation area for each local government area on the basis of competitiveness of agricultural production in comparison with plantations, and impact of returns from carbon trading. At a return of AUS$5 (~ €3) per tonne CO_2, the plantation area in northern NSW is predicted to expand to 180 000 ha.

The objective of this study is to quantify the greenhouse mitigation potential of bioenergy based on the predicted plantation resource in northern NSW. Two alternative bioenergy conversion systems utilising forest and mill residues from timber plantations are compared.

Method

Scope: This study investigates the greenhouse mitigation potential of bioenergy based on residues from plantation forestry in northern NSW. The predicted area and productivity of future plantations, obtained from the ABARE/BRS study of plantation expansion in NSW (ABARE/BRS 2001), formed the basis of the calculation of the potential biomass resource from the region. The FullCAM model (Richards, 2001) was used to simulate the long term GHG balance of bioenergy and conventional forestry systems. Two alternative bioenergy conversion systems, co-firing with coal and wood-fired only, were compared.

Area of plantations

The area of plantations in northern NSW (North Coast and Northern Tablelands districts) was 70 000ha in the year 2000 (National Plantation Inventory 2001). The ABARE/BRS study of potential plantation expansion comprised two components. The first was a spatial analysis of plantation capability and suitability, based on land availability and predicted plantation productivity, in which six plantation productivity classes were identified across NSW: >20, 16-20, 12-16, 8-12, 3-8 and <3 m^3 ha^{-1} mean annual increment (MAI), for Classes 1 to 6. The second component was an economic analysis of the returns from current agricultural enterprises in comparison with plantations. Also included in the assessment was an analysis of the impact of the returns from carbon trading, with an assumed price of AUS$5, 15 or 30 per tonne CO_2. The output of the study was a prediction of the future plantation area in each local government area, for each assumed price of carbon. The ABARE/BRS report did not apportion the area predicted for each local government area into productivity classes, so, for the current study, allocation to productivity classes was based on the relative area of land in each class for that local government area. The current study utilised the predicted plantation area based on a return of AUS$5 per tonne CO_2, at which the plantation area in northern NSW was predicted to expand to 180 000ha (Figure 1). All expansion in the northern region was predicted to occur on sites of productivity class 1 or 2.

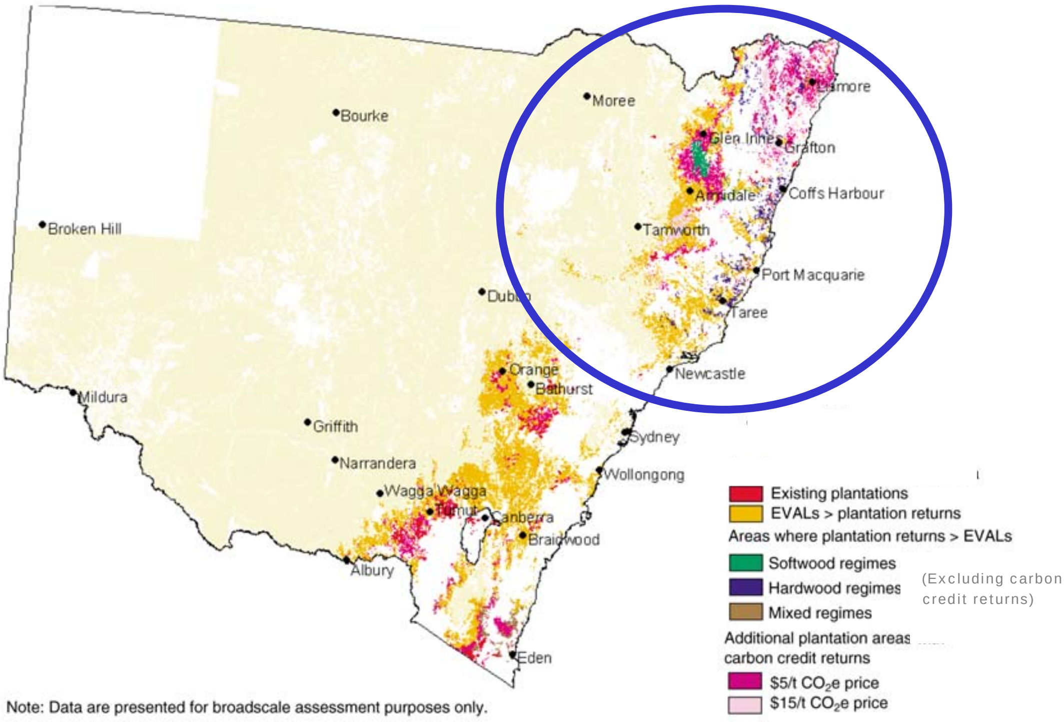

Figure 1 Predicted expansion of plantations in NSW. Study area circled. Assessment based on comparison of forestry returns with estimated value of agricultural land (EVAL). (ABARE/BRS, 2001)

Calculation of GHG balance

The FullCAM model of carbon dynamics (Richards, 2001) was used to calculate the greenhouse gas balance of bioenergy and conventional forestry systems. FullCAM links the process-based model of forest growth, 3PG (Landsberg and Waring 1997), with the forest carbon accounting model CAMFor (Brack and Richards, 2002), and the RothC model of soil organic matter turnover (Jenkinson et al., 1987, 1991). The calculation of displacement of fossil fuel through substitution by bioenergy follows the approach of the model GORCAM (Schlamadinger and Marland, 1996). Input data required are monthly climatic data, soil data, and management events. The model was parameterised using values determined by Paul et al. (2003a and b) for eucalypt plantations in South East Queensland. Plantation growth using this parameterisation was approximately equivalent to mean annual increment of 26 m^3 over a 28 year rotation. Growth curves for each of the productivity classes identified in the ABARE/BRS study were developed by scaling the growth curve obtained under the initial parameterisation data set so that growth to rotation age matched the productivity of each of these classes, simplified to 22, 18, 15, 10 and 5 m^3 MAI for classes 1 to 5 (Figure 2).

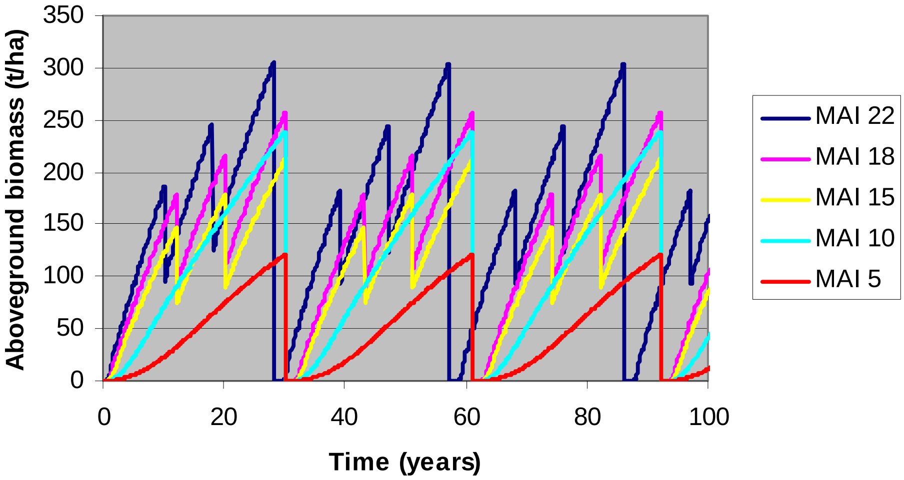

Figure 2 Growth curves for five productivity classes, with MAI of 5, 10, 15, 18 and 22 m3 ha^{-1} $year^{-1}$

The calculation of GHG balance involves comparison of the bioenergy system (the "project case") with a baseline (the "reference case"):

Project case: The project case is a theoretical bioenergy system based on biomass production from conventional hardwood plantation forestry in northern NSW. Biomass is obtained from thinning, harvest and sawmill residues from 70000ha existing and 110000ha newly established hardwood plantations in the region. Two options for energy generation are included:

a) 30MW wood-fired power stations to be constructed within the plantation region, or

b) co-firing in existing 500MW black coal-fired power stations located outside the major plantation region.

Reference case: The reference system to which the bioenergy system is compared represents current practice, in which electricity is generated from 500MW black coal fired power stations; thinning residues decay on the forest floor, harvest residues are windrowed and burned in the field, and sawmill residues that are not utilised in drying timber are burned to waste at the mill. Timber is obtained from 70000ha existing plantations and 110000ha newly established eucalypt plantations.

System boundary: In each case the system boundary includes the power generation system, 70000 ha existing plantation, and 110000 ha grazing land newly converted to plantation. The same quantity of sawn timber is produced, and the same quantity of carbon is sequestered. No credit is claimed for reduced methane emissions due to displacement of cattle by conversion of pasture to plantation, as the cattle population is assumed to remain constant in NSW, and the displacement of cattle applies equally to the reference and bioenergy cases. GHG emissions, including non-CO_2 greenhouse gases, from fossil fuel consumption and fertiliser manufacture and application are included, as are emissions due to power plant construction. CO_2 emissions from combustion of biomass are not included directly in the calculation, on the basis that emissions and removals associated with forest biomass are included as stock change in the forest and wood product pools.

Functional unit: The analysis is expressed in terms of GHG mitigation per hectare of plantation (difference between reference and project case), for each plantation productivity class, and for each of the energy conversion options. Net GHG emissions and GHG emission reductions per MWh_e of bioelectricity for each productivity class and each conversion option are also presented. The calculation period is 100 years, to cover several rotations.

Regional analysis: The regional analysis was undertaken by multiplying the GHG mitigation per hectare with the area of plantation in each productivity class, for each local government area. For the wood- fired option, a transport distance of 100km was assumed for all plantation locations, based on the assumption that these new power stations will be distributed across the region. This transport component was included in the calculation of GHG per hectare for the wood-fired option. For the co-firing option, biomass was assumed to be transported to the existing coal-fired power stations. The transport distance is therefore dependent on the location of the plantations with respect to the coal-fired power stations, and the road network. A spatial analysis was undertaken to determine the mean distance, by existing road network, from each local government area to the closest coal-fired power station (Figure 3); the average distance over which biomass was transported was 360km. The emissions due to transport to the power station were included in the calculation of net GHG balance for each local government area.

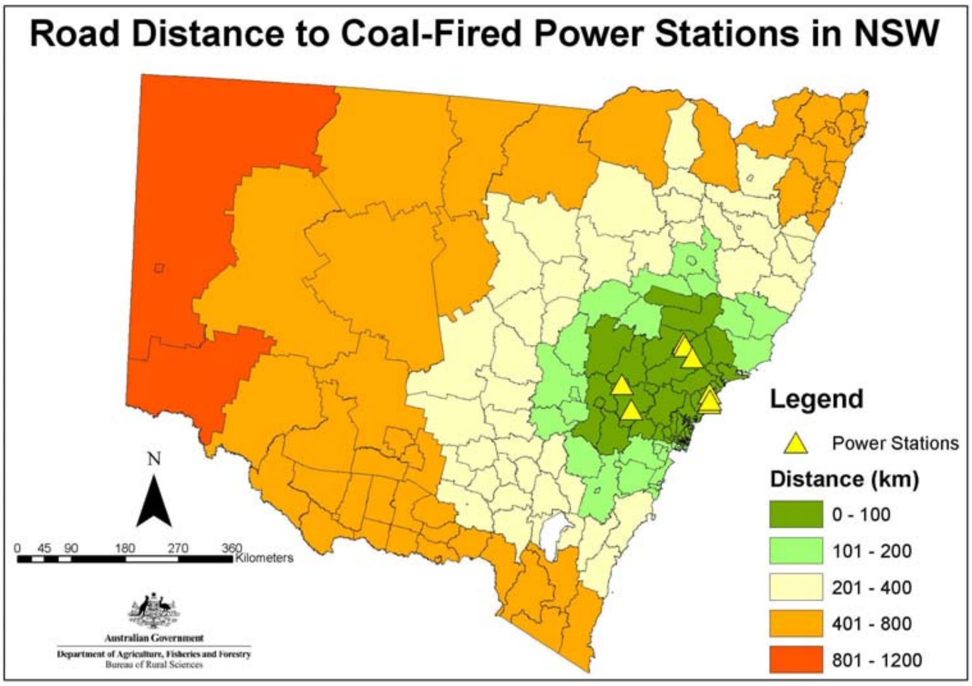

Figure 3 Average road distance to closest coal-fired power station from each local government area in NSW.

Assumptions:

Table 1 lists model parameterisation details for each forestry system. Further details of the sites, model parameterisation and model assumptions are given by Paul et al. (2002, 2003). Harvest recovery, utilisation, service life and landfill decay data were derived from unpublished studies by D. Gardner and F. Ximenes. For the bioenergy case it was assumed that 30% of branch mass, 100% leaf and root mass, and 3% stem mass (representing the stump), remained as litter; at thinning, 100% of the biomass removed from the forest was utilised for bioenergy, while at final harvest, 90% was used for bioenergy and the remainder was retained in sawn wood products. It was assumed that 3.5% of the carbon from mill residues was utilised to dry the sawn timber. The bioenergy and corresponding reference systems each produced the same mass of timber products.

Assumptions for fossil fuel emissions from biofuel production, processing and transport are listed in Table 2, and assumptions associated with the power station options are given in Table 3. It was assumed that biomass was utilised directly from the field rather than being dried prior to combustion; the high moisture content lead to low efficiency of conversion. At 5% co-firing by weight, the efficiency of conversion of coal in the coal-fired plant was assumed to be unaffected by co-firing. Thus, for the co-firing option, the analysis considered only the biomass component of the system: construction relates only to additional facilities required to receive biomass and deliver it to the coal conveyor; the electricity generated and fossil fuel emissions relate only to the biomass combusted.

Table 1 Site and management details for the conventional forestry reference system and bioenergy system.

Initial parameterisation of FullCAM based on Paul *et al* (2003)		
Forestry system	Sawlog eucalypt	
Species	*Eucalyptus grandis*	
Mean annual rainfall (mm)	1138	
Mean annual air temperature (ºC)	20.4	
Soil type	Sandy loam	
Stem density kg DM m^{-3}	700	
Carbon content (%)	Stem Branch Bark Leaf Coarse root Fine root	49 47 49 50 49 46
Initial soil C (tC ha^{-1} 0-30cm)	67.7	
Scaled growth curves used in this study		
Productivity class	1	2
Scaling factor[1]	0.85	0.68
Rotation length (years)	28	30
MAI m^3 ha^{-1} $year^{-1}$	22	18
Thinning (age in years, % biomass removed) Thinning 1 Thinning 2	 10 (50) 18 (50)	 12 (50) 20 (50)
Fate of aboveground biomass at harvest(%)		
Activity	Reference	Bioenergy
Thinning 1 biofuel[2] litter	 0 100	 82 18
Thinning 2 biofuel litter	 0 100	 82 18
ClearFall sawn timber biofuel mill residue[3] litter	 10 0 22 68	 10 75 0.4 15
Fate of products		
Decomposition of product in use (% per year) sawn timber biofuel mill residue	 0.5 na 100	 0.5 10 100
Burned for bioenergy (% per year) sawn timber biofuel mill residue	 0 na 0	 0 90 0
Moved to landfill % per year sawn timber biofuel mill residue	 2 0 0	 2 0 0
Decomposition in landfill % per year sawn timber biofuel mill residue	 0.05 na na	 0.05 na na

[1] applied within FullCAM to initial parameterisation to achieve desired growth rate

[2] Includes harvest residues and sawdust/offcuts from mill utilised off site for bioenergy

[3] Mill residue: sawdust and offcuts burned on site to dry timber (3.5% C in sawn product), remainder burned to waste

Table 2 Emissions from biofuel production, processing and transport

Operation	GHG emission	Reference
Management (plantation establishment and maintenance over the rotation) ($tCO_2e\ ha^{-1}\ year^{-1}$) This value includes the following major components site preparation and planting ($tCO_2e\ ha^{-1}$ per rotation) N_2O emission from applied fertiliser (kg N_2O-N per 100 kg fertiliser N) manufacture of fertiliser (gCO_2e per kg DAP fertiliser)	0.037 1.03 1.25 866	 State Forests NSW, unpublished IPCC 1997 Wood and Cowie 2004
Harvest (tCO_2e per tC in biomass harvested)	0.073	Mike Hall, State Forests, pers. comm.
Chipping and local transport (tCO_2e per tC in biomass processed)	0.037	Mike Hall, State Forests, pers. comm.
Long-distance transport (tCO_2e per tC in biomass transported per km)	0.00073	Mike Hall, State Forests, pers. comm.
Emissions factor diesel ($gCO_2e\ MJ^{-1}$)	78.1	Australian Greenhouse Office 2003
Emissions factor NSW black coal ($gCO_2e\ MJ^{-1}$)	98.1	Australian Greenhouse Office 2003

Table 3 Power station assumptions

	Wood-fired	Co-fired
Technology	Circulating fluidised bed boiler, steam turbine	Pulverised fuel black coal boiler, steam turbine. 5% co-fired biomass, by weight
Capacity	30MW	500MW
Biomass moisture (%)	55	55
Biomass specific energy ($MJ\ kg^{-1}$ DM)	20	20
Efficiency of conversion (%)	20	29.1
Displacement factor[1]	0.57	0.83[2]
Emissions due to construction ($kgC\ MWh_e^{-1}$)	3.27[3]	0.627[4]

[1] Displacement factor = (efficiency of bioenergy system/efficiency of fossil fuel system) x (CO_2 emissions of fossil system/CO_2 from bioenergy)

[2]The displacement factor is lower than one largely due to the high moisture content of the biomass.

[3] Mann and Spath (1997), for Biomass Gasification Combined Cycle plant

[4] M.Mann, pers. comm.

Results and discussion

Table 4 Change in carbon stock of the forest and product pools, and GHG emission from fossil fuel use over 100 years. Positive values indicate an increase in C stock, negative values indicate a decrease in C stock or a GHG emission.

Pool	Productivity Class 1 MAI 22 m^3 ha^{-1} $year^{-1}$						Productivity Class 2 MAI 18 m^3 ha^{-1} $year^{-1}$						Bioenergy case -Reference case			
	Reference		Co-fired		Wood-fired		Reference		Co-fired		Wood-fired		Class 1		Class 2	
	existing	new	existing	new	existing	new	existing	new	existing	new	existing	new	co-fired	wood	co-fired	wood
Soil[1] tC ha^{-1}	-9	-19	-23	-34	-23	-34	-10	-25	-23	-37	-23	-37	-15	-15	-12	-12
Litter[2] tC ha^{-1}	5	5	2	2	2	2	4	4	1	1	1	1	-3	-3	-2	-2
Tree[2] tC ha^{-1}	81	81	81	81	81	81	71	71	71	71	71	71	0	0	0	0
Net forest C tC ha^{-1}	**77**	**67**	**59**	**49**	**59**	**49**	**64**	**50**	**49**	**35**	**49**	**35**	**-18**	**-18**	**-15**	**-15**
Products in use[1] tC ha^{-1}	22	22	25	25	25	25	17	17	20	20	20	20	3	3	3	3
Products in landfill[3] tC ha^{-1}	22	22	22	22	22	22	17	17	17	17	17	17	0	0	0	0
Total Product C tC ha^{-1}	**44**	**44**	**47**	**47**	**47**	**47**	**34**	**34**	**37**	**37**	**37**	**37**	**3**	**3**	**3**	**3**
Fuel used in biomass production tCO_2e ha^{-1}	-53	-53	-236	-236	-76	-76	-45	-45	-197	-197	-64	-64	-184	-24	-151	-18

[1] Value at 100 years determined from fitted trend line, to overcome influence of fluctuating pool size.
[2] Value at 100 years determined from average carbon stock of pool over the period.
[3] Total carbon stock of pool at 100 years.
[4] Includes forestry operations, processing and transport. In the co-firing option, fossil fuel emissions due to transport are calculated for a distance of 360km, which is the average distance from local government area to the closest coal-fired power station, weighted by area of plantations in each LGA.

Table 5 GHG emissions per unit electrical power and per unit of biomass, calculated over 100 years

Pool	Productivity Class 1 MAI 22 m^3 ha^{-1} $year^{-1}$						Productivity Class 2 MAI 18 m^3 ha^{-1} $year^{-1}$						Bioenergy case -Reference case			
	Reference		Co-fired		Wood-fired		Reference		Co-fired		Wood-fired		Class 1		Class 2	
	existing	new	existing	new	existing	new	existing	new	existing	new	existing	new	co-fired	wood	co-fired	wood
Biomass produced tDM ha^{-1}	0	0	1240	1240	1240	1240	0	0	1030	1030	1030	1030	1240	1240	1030	1030
Green electricity generated[3] MWh_e	**0**	**0**	**1889**	**1889**	**1298**	**1298**	**0**	**0**	**1564**	**1564**	**1075**	**1075**	**1889**	**1298**	**1564**	**1075**
Fossil fuel displaced tCO2e ha^{-1}			1853	1853	1273	1273			1534	1534	1055	1055	1853	1273	1534	1055
Net stock change forest+product tCO2e ha^{-1}	443	406	390	352	390	352	361	308	316	263	316	263	-54	-54	-45	-45
Power plant construction emissions tCO_2e ha^{-1}			-4.3	-4.3	-15.6	-15.6			-3.6	-3.6	-12.9	-12.9	-4.3	-15.6	-3.6	-12.9
Emissions $kgCO_2$ $eMWh_e^{-1}$ [a]	**-980**	**-980**	**-128**	**-128**	**-72**	**-72**	**-980**	**-980**	**-128**	**-128**	**-71**	**-71**				
Emissions reduction $kgCO_2$ $eMWh^{-1}$													**853**	**910**	**853**	**910**
Emissions reduction tCO_2e ha^{-1}													**1610**	**1180**	**1335**	**980**
Emissions reduction kgCO2e t $biomass^{-1}$													**1300**	**950**	**1300**	**950**

[a] The additional emissions of the bioenergy case in comparison with the reference case, per unit power generated.

Table 6 Potential bioenergy production from predicted plantation area for each local government area in northern NSW.

Productivity					Class 1		Class 2		Class 1+2	Class 1+2	Class 1+2	Class 1+2
					Co-fired	Wood-fired	Co-fired	Wood-fired	Co-fired	Wood-fired	Co-fired	Wood-fired
Local Government Area	Area Class 1	Area Class 2	Total area	Distance to coal ps	Net GHG balance* after 100 years				Net GHG balance after 100 years		Power produced MWh_e	
	ha	ha	ha	km	ktC	ktC	ktC	ktC	**kt C**			
Armidale	0	0	0	272	0	0	0	0	0	0	0	0
Ballina	1435	0	1435	577	5.92	4.62	0	0	5.92	4.62	27104	18628
Barraba	0	0	0	279	0	0	0	0	0	0	0	0
Bellingen	3126	0	3126	380	13.65	10.06	0	0	13.65	10.06	59043	40580
Bingara	0	0	0	320	0	0	0	0	0	0	0	0
Byron	1882	0	1882	605	7.70	6.06	0	0	7.70	6.06	35547	24431
Casino	112	0	112	557	0.46	0.36	0	0	0.46	0.36	2115	1454
Coffs Harbour	2887	0	2887	404	12.53	9.29	0	0	12.53	9.29	54529	37477
Coonabarabran	0	0	0	248	0	0	0	0	0	0	0	0
Copmanhurst	1042	1700	2742	496	4.40	3.35	5.95	4.54	10.36	7.89	46277	31805
Dumaresq	5728	0	5728	318	25.45	18.44	0	0	25.45	18.44	108190	74357
Dungog	1080	0	1080	65	5.13	3.48	0	0	5.13	3.48	20399	14020
Gilgandra	0	0	0	247	0	0	0	0	0	0	0	0
Glen Innes		52	52	366	0	0	0.19	0.14	0.19	0.14	814	559
Gloucester	447	0	447	136	2.09	1.44	0	0	2.09	1.44	8443	5803
Grafton		3	3	454	0	0	0.01	0.01	0.01	0.01	47	32
Great Lakes	1334	0	1334	109	6.27	4.29	0	0	6.27	4.29	25196	17317
Greater Lithgow	560	3438	3998	17	2.69	1.80	13.70	9.17	16.39	10.98	64362	44235
Greater Taree	6599	0	6599	184	30.40	21.24	0	0	30.40	21.24	124641	85664
Guyra	5068	51244	56312	333	22.43	16.31	187.90	136.73	210.33	153.04	897410	616773
Hastings	5469	0	5469	246	24.79	17.60	0	0	24.79	17.60	103298	70995
Inverell	85	2047	2132	404	0.37	0.27	7.36	5.46	7.73	5.74	33631	23114
Kempsey	3443	0	3443	307	15.35	11.08	0	0	15.35	11.08	65031	44695
Kyogle	8803	0	8803	571	36.39	28.33	0	0	36.39	28.33	166270	114274
Lake Macquarie	4	0	4	15	0.02	0.01	0	0	0.02	0.01	76	52
Lismore	3918	0	3918	579	16.16	12.61	0	0	16.16	12.61	74003	50861

Maclean	484	0	484	494	2.05	1.56	0	0	2.05	1.56	9142	6283
Maitland	2	0	2	42	0.01	0.01	0	0	0.01	0.01	38	26
Manilla	0	0	0	221	0	0	0	0	0	0	0	0
Merriwa	0	0	0	104	0	0	0	0	0	0	0	0
Murrurundi	24	0	24	94	0.11	0.8	0	0	0.11	0.08	453	312
Muswellbrook	0	0	0	38	0	0	0	0	0	0	0	0
Nambucca	4075	0	4075	345	17.98	13.12	0	0	17.98	13.12	76968	52899
Narrabri	0	1	1	309	0	0	0	0	0	0	16	11
Nundle	287	0	287	144	1.34	0.92	0	0	1.34	0.92	5421	3726
Nymboida	4563	0	4563	421	19.70	14.69	0	0	19.70	14.69	86185	59234
Parry	69	0	69	183	0.32	0.22	0	0	0.32	0.22	1303	896
Port Stephens	217	0	217	52	1.03	0.70	0	0	1.03	0.70	4099	2817
Quirindi	2	0	2	133	0.01	0.01	0	0	0.01	0.01	38	26
Richmond River	5014	0	5014	545	20.89	16.14	0	0	20.89	16.14	94704	65089
Rylstone	176	3349	3525	51	0.84	0.57	13.23	8.93	14.07	9.50	55718	38294
Scone	1151	0	1151	69	5.46	3.70	0	0	5.46	3.70	21740	14941
Severn	4750	24940	29690	394	20.67	15.29	89.91	66.54	110.58	81.83	479892	329821
Singleton	6	0	6	23	0.03	0.02	0	0	0.03	0.02	113	78
Tenterfield	8822	0	8822	500	37.24	28.40	0	0	37.24	28.40	166629	114521
Tweed	2559	0	2559	640	10.37	8.24	0	0	10.37	8.24	48334	33219
Ulmarra	1264	0	1264	447	5.42	4.07	0	0	5.42	4.07	23874	16408
Uralla	0	29	29	277	0	0	0.11	0.08	0.11	0.08	454	312
Walcha	5257	0	5257	269	23.67	16.92	0	0	23.67	16.92	99293	68243
Wyong	0	0	0	16	0	0	0	0	0	0	0	0
Total per year	91745	86802	178547		399	295	318	232	718	527	3090838	2124278

* Difference between Bioenergy case and Reference case with respect to the sum of stock change in the forest and product pools, and fossil fuel emissions from biomass production, power plant construction and electricity generation.

Table 7 Potential annual greenhouse mitigation benefit from bioenergy based on plantations in northern NSW

Plantation productivity	Class 1		Class 2		Total Class 1+2	
	Co-fired	Wood-fired	Co-fired	Wood-fired	Co-fired	Wood-fired
Forest + product stock change ‘000t C pa	-13	-13	-11	-11	-24	-24
Fossil fuel emissions displaced ‘000t CO_2e pa	1701	1170	1331	917	3032	2083
Fossil fuel spent ‘000t CO_2e pa	-173	-36	-135	-27	-307	-63
Biofuel produced ‘000t DM pa	1140	1140	893	893	2033	2033
Net GHG balance ‘000t CO_2e pa	1478	1083	1158	849	2636	1932
Electricity produced GWh_e pa	1733	1191	1358	933	3091	2124

The FullCAM model was run for plantation Productivity Classes 1 and 2, for each of the reference, wood-fired and co-fired scenarios for utilisation of forest residues. Results are presented in Tables 4 and 5. Figure 4 exemplifies the stock changes in the forest and product carbon pools, and “bioenergy credit” due to displaced fossil fuel emissions, over 100 years for a plantation of Productivity Class 1, under the co-fired option, with a transport distance from forest to bioenergy plant of 600km.

There was a substantial decline in soil carbon predicted for the reference and bioenergy cases, for newly established forests (Table 4). Reviews of soil carbon dynamics under afforestation have concluded that loss of soil carbon commonly occurs where plantations replace pasture, though large losses are limited to situations where high levels of fertilisation have built up a large pool of labile soil (Guo and Gifford, 2002; Paul et al, 2002; Cowie et al, 2006). Recognising that existing plantations may therefore have a lower initial soil carbon stock than new plantations, separate analyses were undertaken for existing forests (assumed to start with the second rotation) and newly established forests. However, the difference between the reference and bioenergy cases in net stock change for the sum of forest pools was almost identical for new and existing forests (Table 4), so separate results are not presented for the difference between bioenergy and reference cases.

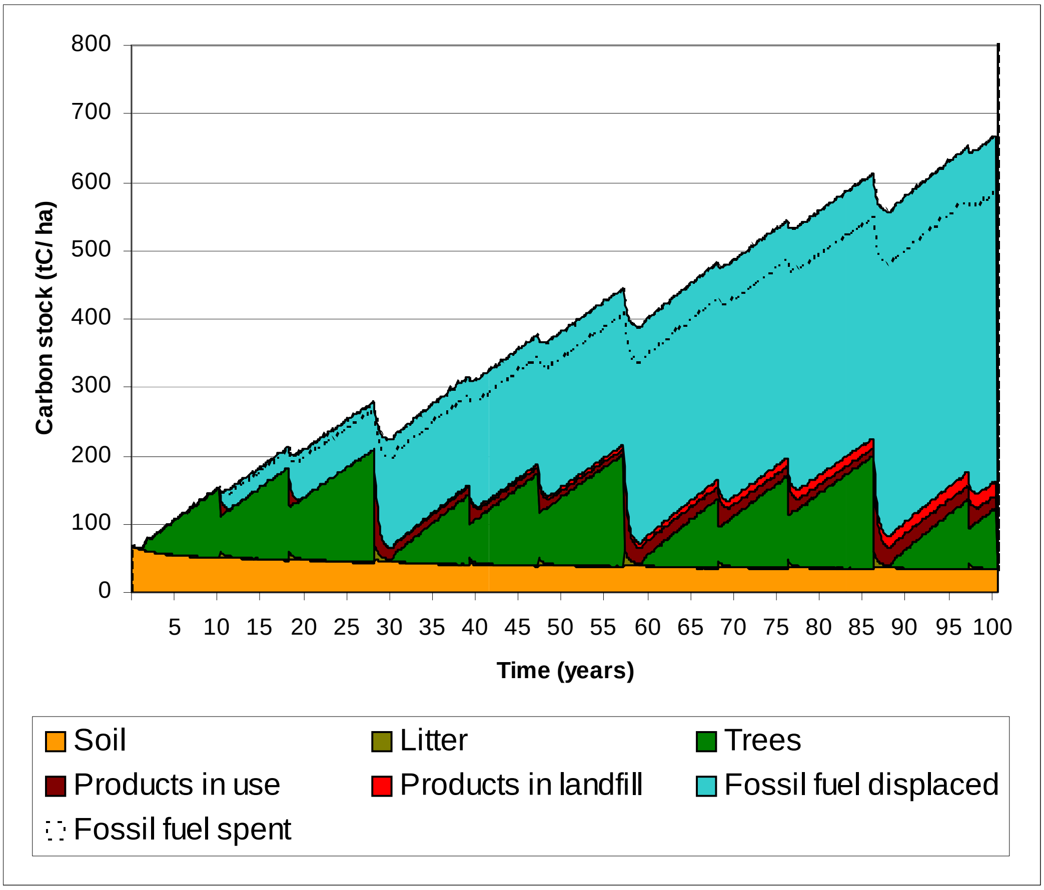

Figure 4 Carbon stock of all forest and product pools, avoided emissions, and fossil fuel spent for the Productivity Class 1, co-fired option, with 600 km transport distance. Fossil fuel spent is a negative value. The net carbon stock is indicated by the broken line.

The rate of decline in soil C was greater under the bioenergy system; this is to be expected, because removal of branch biomass reduces the quantity of biomass C in the litter pool that interacts with the soil C pool. . Nevertheless, changes in the soil C pool are small compared with the accumulation of C in tree biomass over the first rotation, and the growing pools of products. Over several rotations displaced fossil fuel carbon becomes the dominant pool.

By definition, the tree carbon and 'products in landfill' did not differ between the bioenergy and reference cases. The product stock is slightly higher in the bioenergy case due to C stock in the biofuel pool. Emissions due to power plant construction were a small proportion of the total fossil fuel emissions (Table 5).

The net GHG emission reduction for the co-firing option at the highest plantation productivity was 1610 t CO_2-e ha^{-1}, 36% higher than the wood-fired option (Table 5). This difference was due to the higher efficiency of the co-firing system, which was partly offset by higher transport emissions, due to the longer transport distance to coal fired power stations. The emissions from construction, though 3.5 times higher in the wood-fired plant, had very little impact. The total fossil fuel emissions were higher, relative to the power output, for the co-fired option compared with the wood-fired system, so the emissions per unit electricity output were higher for the wood-fired option. Including stock change in the plantation (that is, relative loss of soil carbon compared with the reference system), fuel used in biomass production and transport, and plant construction, the emissions were 128 gCO_2 kWh^{-1} and 72 gCO_2 kWh^{-1} for the co-firing and wood-fired systems, respectively. Considering only the fossil fuel inputs, the emissions are 99 and 31 gCO_2 kWh^{-1} for the co-firing and wood-fired systems, respectively. In comparison, emissions for electricity production from the reference NSW black coal power stations were 980 gCO_2 kWh^{-1}. For advanced technology IGCC (efficiency of 37.2%) fuelled with biomass produced from intensive poplar plantations in the USA, Mann and Spath calculated life-cycle emissions of 49g gCO_2 kWh^{-1} (Mann and Spath, 1997). Published figures for biomass energy systems are generally in the range 20-80 gCO_2 kWh^{-1}. Thus, the emissions from bioenergy systems in the current study are similar to other published figures for bioenergy systems, and about 90% lower than emissions for the coal system that is displaced.

The potential biomass production from 180 000 ha plantations in northern NSW was estimated to be 2.03 Mt per annum (Table 7). The potential power output was estimated at 3090 GWh_e per annum from co-firing, or 2120 GWh_e per annum for the wood-fired option, displacing, respectively, 3.03Mt CO_2-e or 2.08Mt CO_2-e (Table 7). The net GHG emission reduction was 2.63Mt CO_2-e and 1.93Mt CO_2-e per annum for the co-fired and wood-fired alternatives, respectively, which represents 6.0% and 4.4%, respectively, of the 1990 NSW greenhouse gas emissions due to electricity production. The total GHG emission in NSW for 1990, excluding the land use change and forestry sector, was 126.9 $MtCO_2e$; thus, the co-firing option could deliver GHG emission reduction of 2% of this total, while the wood-fired option could give 1.5%. The estimated total quantity of biomass produced is sufficient to supply about ten 30MW power plants.

Uncertainties

Forest carbon stock change

There was a substantial decline in soil carbon predicted for the reference and bioenergy cases. Reviews of soil carbon dynamics under afforestation have concluded that loss of soil carbon commonly occurs where plantations replace pasture, though large losses are limited to situations where high levels of fertilisation have built up a large pool of labile soil carbon. It appears that the model parameterisation utilised in this study reflected such a situation. Thus, it is unlikely that losses of this magnitude will occur on average. However, it is not the absolute change in soil carbon, but the difference between the stock change of the reference and bioenergy systems, that impacts on the net GHG balance of the bioenergy system. The rate of decline in soil C was greater under the bioenergy system; this is to be expected, because removal of branch biomass reduces the quantity of biomass C in the litter pool that interacts with the soil C pool. Nevertheless, changes in the soil C pool are small compared with the accumulation of C in tree biomass over the first rotation, and the growing pools of products. Over several rotations displaced fossil fuel carbon becomes the dominant pool.

In this study, the same allocation of NPP between the tree pools was used for each productivity class. However, there is likely to be greater proportional allocation to roots at lower productivity sites (Zerihun and Montagu, 2004). There is the facility in the FullCAM model to vary the allocation of net primary production between the tree pools for different scenarios, so the parameterisation could be modified to more accurately model the difference in performance between the productivity classes. However, between Classes 1 and 2 this will have little impact.

Non-CO2 greenhouse gases

Non-CO_2 emissions from decay and combustion of biomass have not been included in this study. It is likely that significant CH_4 and N_2O emissions are released in the reference case from residues decaying on the forest floor, harvest slash burned in windrows, and sawmill waste burned in pits or teepee burners. CH_4 emissions will be lower from industrial boilers used in the bioenergy cases, due to more complete combustion of finely divided fuel and higher temperatures, while N_2O emissions will be similar per unit biomass carbon (NGGI 1996a and b). Thus, the inclusion of this source of emissions would increase the net emissions reduction of the bioenergy system, relative to the reference system.

Power plant efficiency

The assumed efficiency of electricity generation in the wood-fired power plant was fairly low, representative of a circulating fluidised bed boiler with steam turbine, utilising green forest residues. More advanced technologies, such as integrated gasification combined cycle systems, have potential to achieve efficiencies in excess of 30%. Pre-drying of feedstock would also increase efficiency of energy conversion.

Regional analysis

The regional analysis of potential for bioenergy from northern NSW is directly dependent on the predicted area and productivity of plantations obtained from the ABARE/BRS study, and therefore strongly influenced by the assumptions behind that study.

Growth rates predicted in the ABARE/BRS study are optimistic in comparison with recent estimates of average plantation growth rates in the region (State Forests NSW Resources Branch, unpublished), though they are achievable with appropriate species-site matching and optimal management. The ABARE/BRS study analysed three options for the price of carbon. Since this study was undertaken, a market for carbon sequestration has been established in NSW through the NSW Greenhouse Gas Abatement Scheme, which imposes mandatory targets for emissions reduction on electricity retailers in NSW. The value of carbon in this market has generally been about AUS$15 per t CO_2, based on the after-tax penalty for non-compliance, though it has dropped to less than $7 in mid-2007 due to an oversupply of offset certificates.

The analysis of plantation expansion did not include the potential returns from supplying biomass for bioenergy. Inclusion of this market option is likely to improve the economic competitiveness of plantations, and increase the predicted plantation area. It would be desirable to repeat the analysis of potential expansion of plantation area with more accurate estimates of plantation capability, current values for agricultural production, and consideration of returns from supply of biomass for bioenergy.

Sensitivity analysis

The sensitivity of the results to some of these uncertainties was examined (Figure 5). Increasing the assumed efficiency of the wood-fired power plant from 20 to 25% gave a corresponding increase in avoided fossil fuel emissions, and increased the emission reduction by just over 25%, to 2.46 $MtCO_2e$ per annum, approaching that of the co-fired option. With advanced integrated gasification combined cycle (IGCC) technology, the efficiency achieved could be as high as that of co-firing; the emissions reduction benefit of the wood-fired option would then surpass that of co-firing, due to reduced transport emissions.

Assuming reduced productivity of the plantations (MAI of 18 rather than 22 m^3 ha^{-1} for Class 1 and 15 rather than 18 for Class 2) the potential biomass production and emission reduction benefits are reduced by nearly 20%.

The ABARE/BRS study predicted that an additional 44 000 ha of plantation would be established at a carbon price of AUS$15 per t CO_2 rather than $5, increasing the area to 222 500ha. This total area could produce 2.54Mt biomass per annum, from which 3870 GWh green electricity may be generated by co-firing or 2660 GWhe from wood-fired power plants, an increase of 25% compared with the area predicted for a carbon price of $5.

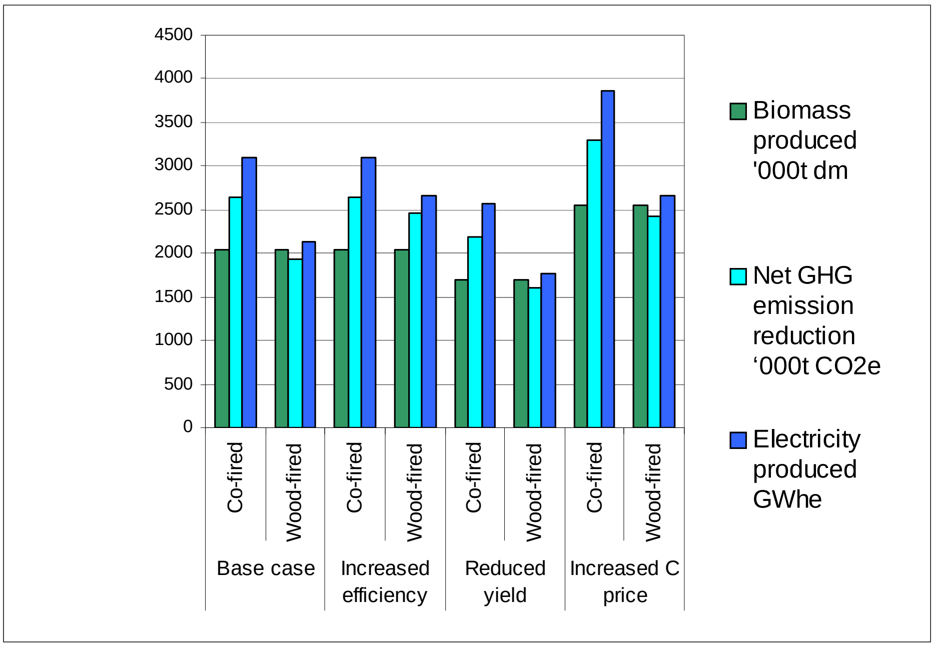

Figure 5 Sensitivity analysis: Biomass produced, GHG emission reduction and electricity produced per annum with increased efficiency of wood-fired combustion, reduced plantation yield and increased carbon price (see text for details).

Conclusion

The expanding plantation industry clearly has potential to contribute significantly to reducing GHG emissions in NSW through supply of biomass for bioenergy: from 180 000ha plantations, through co-firing in existing coal-fired plants, emissions reduction of 2.63MtCO_2e per annum is predicted. The emission reduction benefits are 26% lower for wood-fired power plants, due to the lower efficiency compared with co-firing. This conclusion is dependent on the technology of the wood-fired plant; new generation IGCC technology may achieve similar efficiency to co-firing.

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