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Biofuel excision and the viability of ethanol production in the Green Triangle, Australia

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A B S T R A C T

The promotion and use of renewable energy sources are established priorities worldwide as a way to reduce emissions of Greenhouse Gases and promote energy security. Australia is committed to reach a target of 350 ML of biofuels per year by 2010, and incentives targeted to producers and consumers have been placed. These incentives include zero excise until 2011 for the ethanol produced in Australia and gradual increase of the taxation rates reaching the full excise of 0.125 AUD per litre by 2015. This paper analyses the viability of the second generation ethanol industry in the Green Triangle, one of the most promising Australian regions for biomass production, by comparing the energy adjusted pump prices of petrol and the produced ethanol under different taxation rates and forecasted oil prices. Major findings suggest that under the current conditions of zero fuel excise and oil prices around 80US$ per barrel ethanol production is viable using biomass with a plant gate cost of up to 74 AUD per ton. Moreover, the forecasted increase in oil prices have a higher impact on the price of petrol than the increased ethanol excise on the pump price of the biofuel. Thus, by 2016 feedstock with a plant gate cost of up to 190 AUD per ton might be used for ethanol production, representing a flow of 1.7 million tons of biomass per year potentially mitigating 1.2 million tons of CO_2 by replacing fossil fuels with ethanol.

1. Introduction

The promotion and use of renewable energy sources are established priorities worldwide. Australia's *Biofuels Action Plan* is committed to reach a target of producing 350 ML of biofuels per year by 2010. In order to achieve that target, some federal initiatives have been implemented among the Australian ethanol and biodiesel producers for example the Ethanol Production Grant Program and the Cleaner Fuels Grant Program pay these producers 38.143 AUD cents per litre of ethanol and biodiesel. In addition, to promote demand and increase the competitiveness of biofuels against petrol, biofuels are excise free until 2011 and a calendar of increased taxation has been defined reaching a full excise of AUD 12.5 cents per litre in 2015 (ATO, Australian Taxation Office 2006).

Transport is the second largest emitter of energy related Greenhouse Gases in Australia and it is a sector extremely dependent on oil. The increasing demand for fossil fuels makes the Australian sources of oil and gas insufficient, and second generation biofuels might play an important role to reduce emissions and promote fuel security without significant impact on food availability (Batten and O'Connell, 2007).

The estimation of the potential of a region for second generation ethanol production depends on the land available for growing biomass, the production levels of the different biomass types and the process yields, but also on the economic competitiveness of the ethanol generated from biomass. Thus, domestic policies like biofuel taxation levels and external factors like the international price of oil play a major role in the development of a biofuel industry. In this regard, considering the existing federal incentives and based on its current timber and agricultural production, the Green Triangle, an area of south-east South Australia and south-west Victoria, is a promising region in terms of biomass flow for ethanol production.

The aim of this paper is to estimate the competitiveness of the ethanol industry considering the availability of biomass and the Australian biofuels taxation calendar in the context of the forecasted international prices of oil.

The paper is structured as follows: Section 2 presents the availability of biomass in the Green Triangle and the cost of the different feedstock. Section 3 develops an *ex ante* analysis of ethanol production costs and estimates the breakeven price of oil and biomass to be competitive with petrol under different oil prices and excision rates. Finally, Section 4 discusses major findings and concludes.

2. Biomass availability and costs

2.1. Case study region

The Green Triangle region covers an area of about 6 million hectares in south eastern South Australia and western Victoria

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and included three separate statistical divisions (SD): South East, Wimmera and Western District. This region was selected because it has high potential for the production of biomass based on a large well developed forest industry in the south based on softwood and hardwood plantations, and major grain growing region in the north (Fig. 1).

The region is well connected by roads and rail and the port of Portland is an important export terminal. The total population is 210,000 with Mount Gambier in South Australia and Warrnambool in Victoria, the largest towns each with populations of more than 20,000. Forestry industries include sawmilling, wood panels, pulp and paper manufacture and wood chip export while agricultural industries include beef, dairy, wheat, canola, viticulture and horticulture.

2.2. Forest and agricultural biomass availability

The Almeida et al. (2007) 3-PG2 model calibrated for the Green Triangle conditions by Polglase et al. (2008) was used to spatially estimate the supply of biomass from currently planted forest land in the Green Triangle following the methodology described by Rodriguez et al. (accepted for publication). Sawmill residues were disaggregated in sawdust, chips, bark and shavings based on information about the breakdown of sawlogs into sawmill residues and sawn timber collected from individual sawmills in the region (Table 1).

Crop stubble – the fibrous stalk, leaf and chaff material left after grain (or other products) have been harvested – is an agricultural source of lignocellulose biomass for second generation biofuels. The annual flow of harvestable stubble in the Green Triangle was estimated following the methodology described by Dunlop et al. (2008) considering that at least 1 ton of attached stubble per hectare is left in-field and 20% of the chaff is not collected because of mechanical limitations.

2.3. Biomass costs

The costs of the different biomass types was estimated based on published literature complemented with information provided by forest managers and farmers operating in the region. For products with existing markets (i.e. sawlogs, pulplogs, sawlogs, chips, sawdust and bark) current market prices were obtained through a survey of forest growers and sawmills in the Green Triangle region. The cost of forest residues were calculated following Hall et al. (2001) and Blomqvist (2007) based on the different harvest practices currently used in the Green Triangle.

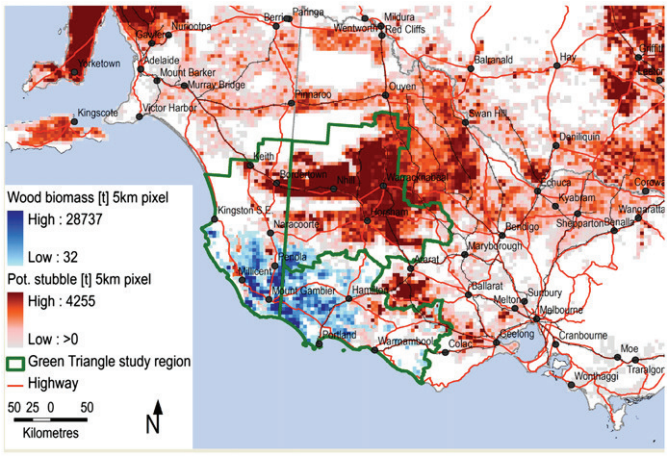

Fig. 1. Land use in the Green Triangle.

Table 1
Average proportions of different sawmill residues, their estimated moisture contents and average price. Data based on a survey mills in the region.

Type	Proportion	Moisture content	Cost	
	% Dry weight	%	AUD per ton wet weight	AUD per ton dry weight
Chips	43	53	37	79
Bark	7	30	11	16
Green sawdust	10	55	11	24
Shavings	3	12	21	23
Sawn timber	38	21	NA	NA
Total	100			

Changes in the price of oil will increase/decrease the cost of producing and transporting biomass. The transport costs were estimated using a model developed by Lambert and Quill (2006) and expressed in AUD per ton/km. The initial cost of transporting the logs and woodchips was estimated to be around 13 cents AUD per ton/km while that for forest and crop residues was 23 cents AUD per ton/km. The higher cost of the latter is due to the longer time needed to load trucks with small, non-uniform material, longer loading time and lower bulk density of baled agricultural residues (0.5 ton/m^3) compared with logs (1.0 ton/m^3 green). Costs of forest biomass were adjusted to changes in oil prices considering that 1 m^3 wood requires 0.9 L fuel for growing, 3.1 L for harvesting and 3.0 L for chipping, and that 1 ton of agricultural residues require around 3.3 L for harvesting and 1 L of fuel for bailing 1 ton of stubble.

The availability and cost of the different biomass sources are presented in Table 2.

The amount of available cheap biomass and the cost of transporting the required feedstock are strong limitations for the size of bioenergy projects (e.g. Gan, 2007). Based on the availability of forestry and agricultural feedstock, and the proximity to port and road networks, Mount Gambier was selected as a study case to assess the capacity of different biomass feedstock to contribute to ethanol production and promote energy security in Australia

A 68 million litres/year second generation enzymatic ethanol plant with a conversion efficiency of 325 L ethanol/ton of biomass was considered for this study. The selected technology is appropriate for large scale operations and can be adjusted to use different feedstock types (S&T Consultants Inc., 2007).

2.4. Mount Gambier biomass supply curves

There is more than 2.6 million tons of biomass produced every year within 200 km radius from Mount Gambier (Fig. 2). Agricultural residues represent about 38% of the total biomass. They are available at a plant gate cost between 84 and 106 AUD ton depending on the farm distance from Mount Gambier. Hardwood pulplogs are the most expensive feedstock with a market value exceeding 200 AUD/ton; they represent about 40% of the produced forest biomass and most of them are transported to Portland to be exported as woodchips. Softwood pulplogs are mostly used to manufacture paper products; they represent about 21% of the total forest biomass and might be available in the range between 116 and 150 AUD dry ton. The combined sawmill residues represent over 520 thousand tons of biomass every year. There is usually an annual production of about 360 thousand tons of woodchips with a plant gate cost of about 89 AUD/ton being the most expensive of the sawmill residues. They are currently sent to Portland for export or used locally by the particleboard

Table 2
Amount and baseline cost of different feedstocks within the Green Triangle case study region and the pump prices of ethanol produced with them after adjusting by energy content.

Feedstock type	Distance (km)	Amount thousand tons per year dry weight	Farm gate cost feedstock[a] AUD/ton dry weight	Transport costs AUD/ ton dry weight	Plant gate cost AUD/ ton dry weight	Ethanol energy adjusted pump price AUD/litre
Hardwood plantations						
Pulplogs						
	50	92.59	180.00	12.97	192.97	1.87
	100	428.88	180.00	21.71	201.71	1.92
	150	113.43	180.00	30.46	210.46	1.97
	200	9.82	180.00	39.20	219.20	2.02
Forest residues						
	50	8.33	17.44	19.45	36.89	1.06
	100	38.60	17.44	27.62	45.05	1.10
	150	10.21	17.44	35.78	53.21	1.15
	200	0.88	17.44	43.97	61.40	1.19
Softwood Plantations						
Pulplogs						
	50	261.62	100.00	16.22	116.22	1.47
	100	85.57	100.00	27.14	127.14	1.53
	150	12.02	100.00	38.08	138.08	1.59
	200	0.00	100.00	49.00	149.00	1.65
Harvest residues						
	50	43.66	23.18	21.22	44.40	1.10
	100	14.18	23.18	30.13	53.31	1.15
	150	2.04	23.18	39.03	62.21	1.20
	200	0.00	23.18	47.96	71.15	1.24
Sawmill residues						
Chips	10	362.24	80.00	8.74	88.74	1.33
Bark	10	55.10	19.00	5.90	24.90	0.99
Green sawdust	10	80.49	25.00	9.17	34.17	1.04
Shavings	10	21.74	24.00	4.69	28.69	1.01
Agricutural residues						
Crop stubble						
	50	62.96	70.00	13.70	83.7	1.30
	100	126.00	70.00	21.24	91.24	1.34
	150	378.00	70.00	28.78	98.78	1.39
	200	1133.00	70.00	36.33	106.33	1.43

[a] Includes cost of growing, harvesting, handling and chipping.

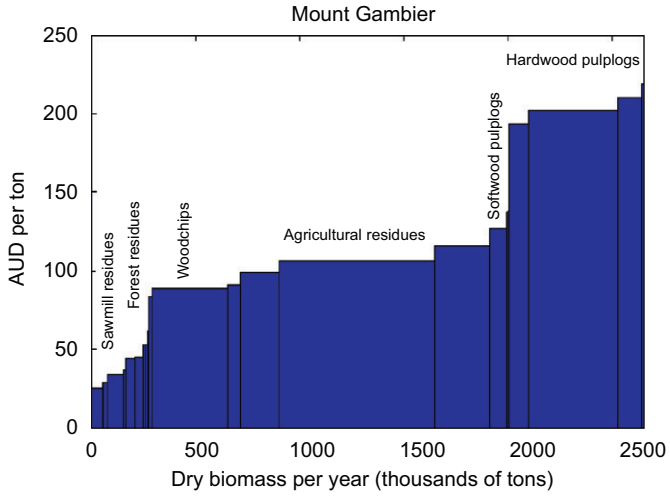

Fig. 2. Biomass cost curve for Mount Gambier.

industry. The harvest residues collected from softwood and hardwood plantations represent, respectively, about 2.1% and 2.2% of the total biomass in the Green Triangle. These residues are usually pieces of over 8 cm of small end diameter and commercialized at a plant gate price of over 44 AUD/ton for the softwood and 37 AUD/ton for the hardwood.

3. Comparative transport fuel production costs

3.1. Petrol price pump

Pump petrol price in Australia was estimated based on the oil price (79 US$ barrel, and current refining petrol costs (0.03–0.04 AUD per litre) *ex Singapur*, after considering the exchange rate (0.88 AUD/US dollar), the shipping and other associated costs (0.082 AUD per litre), the costs of distributing the petrol within Australia (0.01 AUD per litre), the associated taxes: the national fuel excise (0.381 AUD per litre) and the 10% General Sales Taxes, as well as a 5% retailers margin, representing a pump price of about 1.24 AUD per litre (December 2009) (Table 3).

3.2. Biomass ethanol costs

The production cost of ethanol largely depends on the plant gate cost of the different biomass feedstock, that for the Green Triangle are in the range between 25 and 220 AUD (Table 2). This study focuses on ethanol production using a 68 million litres per year second generation enzymatic plant with a yield of 325 L of ethanol per ton of biomass, an optimal size and expected

conversion efficiency for this technology. Therefore, about 210,000 tons of biomass per year is required to operate the plant. The capital costs and operating costs (excluding biomass) for such a plant were estimated as 0.28 and 0.13 AUD per litre, respectively, based on published information (S&T Consultants Inc, 2007) for an AUD 226 million plant with a plant life of 30 years and an annual interest rate of 7.5%.

The ethanol pump price was estimated based on the production cost of ethanol and assuming similar distribution costs, general sales tax and retailer margin than petrol. Ethanol excise rate was defined based on the existing taxation calendar for biofuels (ATO, 2006). Considering that the energy content of petrol is around 34.2 MJ per litre and that of ethanol is just 23.4 MJ per litre (Department of Climate Change, DCC 2009), the pump price was adjusted by a factor of 1.46 to allow comparisons with petrol price in equal energy terms.

Biomass cost is an important factor in the production costs of ethanol. After adjusting by their energy content, the pump prices of ethanol produced using the different available feedstock are presented in Table 2. It is then clear that not all the feedstock types are able to be used for ethanol production in an economically viable manner because of their high cost that make them not competitive with petrol.

Table 4 shows an analysis of the petrol and ethanol energy adjusted pump prices considering the international price of oil and plant gate cost of biomass. At the 2009 oil price of 79 US$ barrel and considering the current zero excise for biofuels, the production of ethanol is viable using biomass with a plant gate cost of up to 74 AUD per ton (i.e. with a production cost of about AUD 0.64 per litre and a pump price of AUD 1.24 after adjusting per energy content). This suggests that only about 500,000 tons of biomass per year comprising mostly sawmill residues and hardwood and softwood forest harvest residues might be used for ethanol production. A sensitivity analysis suggests that a 10% and 20% increase in the price of oil will represent that biomass with a plant gate cost of up to 85 and 97 AUD per ton might be used for ethanol production, totaling 583,000 and 693,000 tons of biomass per year. On the other hand a 10% and 20% decrease in the price of oil, reaching pump petrol prices of around AUD 1.1 AUD per litre will represent that ethanol production is viable using only biomass of up to 60 and 47 AUD per ton, respectively, nevertheless there are only 233,000 tons of biomass available at that low price.

Table 3
Variables and Parameters for the estimation of petrol pump prices.

Unleaded petrol (ULP)	Unit	Value
Variables		
Oil price per barrel ex Singapore	US$/barrel	79
Australian fuel excise rate	AUD/litre	0.381
Parameters terminal gate price		
Exchange rate	US$/AUD	0.88
Volume conversion: barrels to litres	Litres/barrel	159
Refining cost Petrol ex Singapore	AUD/litre	0.04
Shipping et al. costs per litre	AUD/litre	0.082
Australian fuel distribution cost	AUD/litre	0.1
Australian 10% GST	AUD/litre	0.107
TERMINAL GATE PRICE	AUD/litre	**1.18**
Parameters pump price		
5% Retailers' margin of terminal gate price	AUD/litre	0.059
RETAIL PUMP PRICE	AUD/litre	**1.249**

RETAIL PUMP PRICE=TERMINAL GATE PRICE+Retailer's margin.
Retailers margin=0.05(TERMINAL GATE PRICE).
TERMINAL GATE PRICE=petrol cost ex Singapore litre+shipping costs+Australian distribution costs+fuel excise rate+Australian GST.
Australian GST=0.1(petrol cost ex Singapore+shipping costs+Australian distribution costs+fuel excise rate).
Petrol cost ex Singapore litre=(oil price∗1/exchange rate/volume conversion) +refining costs of petrol.

3.3. Ethanol production and taxation calendar

Biofuel excise and the international price of oil can affect the competitiveness of ethanol industry. The Australian biofuels excise has been designed considering their difference in energy content in relation to fossil fuels in order to keep similar the excise payable by kilometer traveled with different fuels. Thus considering the excise rate of petrol as 38.143 AUD cents per litre, the full excise for ethanol was estimated as 12.5 AUD cents per litre (ATO, 2006) and will be placed following the calendar presented in Table 5.

Table 5
Australian ethanol excision rates and calendar.

Fuel	Unit	July 2010	July 2011	July 2012	July 2013	July 2014	July 2015
Ethanol	AUD per litre	0	0.025	0.05	0.075	0.10	0.125

Table 4
Breakeven and sensitivity analysis of petrol and ethanol energy adjusted pump prices considering the forecasted international price of oil, the plant gate cost of biomass and the ethanol excise rates.

	Oil price US$ barrel	Petrol pump price AUD per litre	Ethanol pump price AUD per litre	Biomass plant gate cost AUD/ Ton	Available tons
2009: 0 excision ethanol	79	1.24	1.24	74	500.5
10% Increase oil price	86.9	1.30	1.30	85	583.4
20% Increase oil price	94.8	1.37	1.37	97	693.5
10% Decrease oil price	71.1	1.17	1.17	60	356.2
20% Decrease oil price	63.2	1.10	1.10	47	233.0
2012: 5 cents per litre excision ethanol	105	1.45	1.45	100	868.5
10% Increase oil price	115.5	1.54	1.54	116	980.5
20% Increase oil price	126	1.62	1.62	132	1101.8
10% Decrease oil price	94.5	1.36	1.36	82	765.9
20% Decrease oil price	84	1.28	1.28	66	583.0
2016: 12.5 cents per litre excision ethanol	175	2.03	2.03	190	1723.3
10% Increase oil price	192.5	2.17	2.17	216	1931.6
20% Increase oil price	210	2.32	2.32	245	2380.6
10% Decrease oil price	157.5	1.88	1.88	160	1385.4
20% Decrease oil price	140	1.74	1.74	134	1236.8

The oil prices are also expected to increase over time. The forecasted prices expressed in 2009 US$ per barrel are US$105 for the year 2012 (Allidina and Kleinman, 2009) and US$ 175 for the year 2016 (Deutsche Bank, 2009). Therefore, expressing the cost of biomass and the cost of oil in 2009 currencies it is possible to explore the viability of a second generation ethanol industry in the Green Triangle under different taxation levels and oil prices.

3.3.1. Ethanol excise of AUD 5 cents per litre

Table 6 shows a sensitivity analysis of the petrol and ethanol energy adjusted pump prices considering the international price of oil, the plant gate cost of biomass and the AUD 5 cents per litre excise for ethanol. This condition corresponds to year 2012 when oil prices are forecasted to reach 105 US$ barrel (Allidina and Kleinman, 2009) and petrol pump prices about 1.45 AUD per litre following the parameters presented in Table 3.

The increment in oil prices will raise the production and transport cost of biomass incrementing the ethanol energy adjusted pump prices between 0.07 and 0.15 AUD per litre depending on the feedstock and distance while petrol pump prices are expected to increase 0.27 AUD per litre in relation to the baseline of zero ethanol excise and 1.24 AUD per litre petrol pump price. In these conditions, the production of ethanol is viable using biomass with a plant gate cost of up to 100 AUD per ton. Therefore woodchips and stubble might be used along with sawmill and forest harvest residues for ethanol production representing a flow of biomass of about 868,000 tons per year. The analysis indicates that a 10% increase or decrease in the price of oil will represent that biomass with a plant gate cost of up to 116 and 82 AUD per ton might be used for ethanol production totaling 980,000 and 765,000 tons of biomass per year, respectively, while a 20% decrease in the price of oil represents that ethanol industry might be viable using biomass of up to 66 AUD per ton i.e. only using sawmill residues and forest harvest residues representing about 583,000 tons per year.

3.3.2. Ethanol excise of AUD 12.5 cents per litre

Table 7 shows a similar analysis of the petrol and ethanol energy adjusted pump prices under the full ethanol excise of AUD 12.5 cents per litre, the taxation rate that will be in placed from year 2015 onwards. Thus, for 2016 when oil prices are forecasted to reach 175 US$ barrel (Deutsche Bank, 2009), the pump price of petrol in Australia will rise up to 2.03 AUD per litre following the parameters presented in Table 3. The oil price increment will increase the energy adjusted pump price of ethanol between 0.19 and 0.31 AUD per litre due to the increased production and transport cost of biomass, while petrol pump prices will have a larger increment i.e. about 0.79 AUD per litre in relation to the baseline of zero ethanol excise and 1.24 AUD per litre petrol pump price (Table 7). In these conditions, is expected that biomass of higher prices i.e. up to 190 AUD per ton might be used for ethanol production representing 1,723,000 tons of biomass per year comprising all the feedstock types with the exception of hardwood pulplogs. However, the sensitivity analysis shows that if the oil price increases 10% or 20%, biomass with a plant gate cost of up to AUD 216 and AUD 245 per ton i.e. hardwood pulplogs located within 100 km from Mount Gambier, might be used for ethanol production, representing an additional

Table 6
Increased biomass and ethanol production costs in the Green Triangle under oil prices of 112 US$ per barrel and ethanol excision rate of 0.05 AUD per litre.

Oil price US$ 112 and ethanol excision rate 0.05 AUD per litre	Distance	Tons	Increased production costs AUD/ton	Increased transport costs	Biomass plant gate cost AUD/ton	Ethanol production costs AUD per litre	Increased ethanol production cost AUD per litre
Hardwood plantations							
	50	208.235	190.95	14.27	204.62	2.00	0.13
	100	219.095	190.95	24.30	214.48	2.06	0.14
	150	229.9549	190.95	34.33	224.34	2.11	0.14
	200	240.8149	190.95	44.36	234.21	2.16	0.15
Forest residues							
	50	42.11555	20.18	20.63	40.55	1.15	0.09
	100	52.22965	20.18	29.98	49.75	1.20	0.09
	150	62.34376	20.18	39.34	58.95	1.24	0.10
	200	72.45786	20.18	48.69	68.15	1.29	0.10
Softwood plantations							
Pulplogs						0.94	
	50	135.0174	113.45	17.83	130.55	1.62	0.15
	100	148.5924	113.45	30.37	142.88	1.68	0.15
	150	162.1673	113.45	42.91	155.21	1.75	0.16
	200	175.7423	113.45	55.45	167.54	1.81	0.16
Harvest residues							
	50	49.80021	25.92	22.51	48.15	1.19	0.09
	100	60.83378	25.92	32.71	58.19	1.24	0.10
	150	71.86735	25.92	42.91	68.23	1.29	0.10
	200	82.90092	25.92	53.12	78.26	1.34	0.10
Sawmill residues							
Chips	10	89.27877	80.00	9.08	89.05	1.40	0.07
Bark	10	25.23003	19.00	6.10	25.07	1.07	0.07
Green sawdust	10	34.69116	25.00	9.49	34.45	1.12	0.07
Shavings	10	28.9557	24.00	4.85	28.83	1.09	0.07
Agricutural residues							
Crop stubble							
	50	93.26886	76.48	14.79	90.87	1.41	0.11
	100	102.605	76.48	23.43	99.37	1.45	0.11
	150	111.9411	76.48	32.06	107.86	1.50	0.12
	200	121.2771	76.48	40.69	116.36	1.54	0.12

Table 7
Increased biomass and ethanol production costs in the Green Triangle under oil prices of 175 US$ per barrel and ethanol excision rate of 0.125 AUD per litre.

Oil price US$ 175 and ethanol excision rate 0.125 AUD per litre	Distance	Tons	Increased production costs AUD/ton	Increased transport costs	AUD/ ton	Ethanol production costs AUD per litre	Increased ethanol production cost AUD per litre
Hardwood plantations							
	50	208.235	194.72	15.70	210.41	2.14	0.27
	100	219.095	194.72	27.16	221.87	2.20	0.28
	150	229.9549	194.72	38.62	233.33	2.26	0.29
	200	240.8149	194.72	50.08	244.79	2.32	0.31
Forest residues							
	50	42.11555	21.12	21.94	43.06	1.27	0.21
	100	52.22965	21.12	32.60	53.72	1.33	0.22
	150	62.34376	21.12	43.27	64.39	1.38	0.23
	200	72.45786	21.12	53.93	75.05	1.44	0.24
Softwood plantations							
Pulplogs							
	50	135.0174	118.09	19.62	137.71	1.76	0.29
	100	148.5924	118.09	33.95	152.03	1.84	0.31
	150	162.1673	118.09	48.27	166.36	1.91	0.32
	200	175.7423	118.09	62.59	180.68	1.99	0.33
Harvest residues							
	50	49.80021	26.86	23.94	50.79	1.31	0.21
	100	60.83378	26.86	35.57	62.43	1.37	0.23
	150	71.86735	26.86	47.20	74.06	1.43	0.24
	200	82.90092	26.86	58.83	85.69	1.49	0.25
Sawmill residues							
Chips	10	89.27877	80.00	9.42	89.42	1.51	0.19
Bark	10	25.23003	19.00	6.32	25.32	1.18	0.19
Green sawdust	10	34.69116	25.00	9.84	34.84	1.23	0.19
Shavings	10	28.9557	24.00	5.03	29.03	1.20	0.19
Agricutural residues							
Crop stubble							
	50	93.26886	78.71	16.00	94.71	1.54	0.24
	100	102.605	78.71	25.85	104.55	1.59	0.25
	150	111.9411	78.71	35.69	114.40	1.64	0.26
	200	121.2771	78.71	45.53	124.24	1.69	0.27

flow of 208,000 and 657,000 tons of biomass per year, respectively. On the other hand, a 10% or 20% decrease in the price of oil reaching prices of 157 and 140 US$ barrel might decrease the amount of available biomass to 1,235,000 and 1,386,000 ton, respectively, since feedstock with a plant gate cost of up to 160 and 134 AUD per ton might be used for ethanol production.

4. Discussion

The results of this research indicate that under the current zero taxation rate of ethanol and oil prices around US$ 80 barrel, the development of an ethanol industry in the Green Triangle is viable using biomass with a plant gate cost of up to 74 AUD per ton. Our estimates of biomass in the Green Triangle indicate that less than 20% of all the biomass produced i.e. only 500,000 tons per year comprising mostly sawmill residues and hardwood and softwood forest harvest residues might be potentially available at the required price, while other feedstock might be too expensive. However, much of these cheap feedstock currently have uses and applications in diverse industries, limiting the amount that could be practically diverted to ethanol production. In many parts of Australia only 15% of the sawmill residues might be available for bioenergy since most of them are currently used by the plywood, particleboard, potting mix and paper industries (NAFI, 2005), on the other hand most of the forest harvest residues are not collected because of there is no market for them and kept on site to maintain soil fertility. Thus, conservative assuming that half of the forest harvest residues and 15% of the sawmill residues might be diverted to ethanol production, they represent a flow of around 219,000 tons per year, covering the requirements of an ethanol plant producing 68 million litres per year.

The changes in oil prices modify the amount of biomass that could be used for ethanol production by increasing or decreasing the competitiveness of petrol in relation to ethanol, finally affecting the appropriate size of ethanol plants. Thus, if the price of oil decreases 10%, the amount of feedstock that could be diverted to ethanol production might be reduced to a total of about 147,000 tons per year covering only about 70% of the required biomass for a 68 million litre plant, while on the other hand an increase in 10% oil prices will represent that around 230,000 tons of biomass might be available and an ethanol plant 9% bigger might be viable in the Green Triangle.

The Australian federal biofuel policies are designed to achieve the National target of 350 million litres of biofuels by 2010 through a combination of payments to producers and zero excise for biofuels to increase their competitiveness against petrol (ATO, 2006). Incentives to develop a biofuel industry are commonly used around the world. They are implemented as volumetric mandates or price/tax subsidies to provide competitive advantages to desirable fuel types (see Tyner and Viteri, 2010). The level of these incentives as well as the price of oil certainly affects the viability of the use of biomass for ethanol production (e.g. Slade et al., 2009). Based on forecasted oil prices and the Australian biofuel taxation calendar our analysis suggests that for the same percentage of increment in oil prices, the price of petrol will increase more than the production costs of ethanol despite its increased taxation, and in the future biomass with higher plant

gate cost might be used for ethanol production. Thus, by 2012 when Australian pump petrol prices reaches around 1.45 AUD per litre because of the forecasted increment in the international oil prices, the production of ethanol in the Green Triangle might include other feedstock such as agriculture residues, increasing the resource base in about 368,000 additional tons equivalent to 119.6 million litres of ethanol per year. In a similar way by 2016 when the full ethanol excise will be in placed and oil price forecasted to reach about 175 US$ per barrel, there would be around 2.3 million tons of biomass in the Green Triangle that could be potentially used for ethanol production in an economically viable way representing a total potential for around 747 million litres of ethanol per year. However, there are many forest industries already operating in the Green Triangle including, wood panels, pulp and paper manufacture and wood chip for export that make use of the existing biomass and the precise amounts of feedstock that could be diverted for ethanol production is a subject of further studies.

The costs of ethanol production are dependent of the involved feedstock and technology. For the enzymatic second generation plant considered in our study, the cost of ethanol from forest products are in the range between 0.5 and 1.00 AUD per litre for sawmill residues and hardwood pulplogs, respectively, while for agricultural residues the ethanol production costs are in the range between 0.67 and 0.75 AUD per litre depending on the transport distance of the biomass. These production costs for the Green Triangle are in the range of the reported for other enzymatic lignocellulosic studies around the world for similar plant sizes (e.g. Sassner et al., 2008; Wingren et al., 2003; Mondal et al., 2010). However, variations in the range US$ 0.13–0.8 per litre in the production cost of ethanol could be expected based on the different capital costs associated to plants of different sizes, and the type and variation in the cost of the feedstock used (Gnansounou, 2010).

Slade et al. (2009) highlight the point that the best performing feedstock could be competitive with petrol but there is a need for location specific assessment of feedstock availability and price. In this regard, our studio shows the different breakeven prices and abundance of biomass for ethanol production suggesting that an ethanol industry might be viable under different combinations of biofuel taxation rates and oil prices. The promotion and use of biofuels as a way to reduce emissions of Greenhouse Gases by replacing fossil fuels is an established priority around the world. Considering their returns on energy invested and energy content in relation to petrol, the mitigation potential of ethanol in Australia was estimated as 1.66 kg CO_2 per litre of ethanol (O'Connell et al., 2009; Farine et al., in press). Thus, in the current conditions, a 68 million litres plant of ethanol in the Green Triangle could contribute to mitigate 0.11 million tons of CO_2 per year, while in the future the potential might increase up to 1.2 million tons of CO_2 per year if the price of oil allows that most of the biomass might be economically used for ethanol production as forecasted by 2016.

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