ABARE conference paper 09.1

AARES Australian Agricultural and Resource Economics Society

11–13 February 2009, Cairns, Queensland

Assessing the environmental externalities from biofuels in Australia

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Keywords: *biofuels, environmental policy, greenhouse gas emissions, air pollutants, externalities, Australia*

In Australia, as in other countries, the environmental costs and benefits of biofuel production and use have been found to vary greatly according to the production method and feedstocks used. In general, the use of biodiesel produced in Australia has been found to provide greater environmental benefits than ethanol, both in terms of reduced greenhouse gas (GHG) emissions and reduced air pollutant emissions. In this paper, estimates of GHG and air pollutant emissions arising from biofuels and petroleum fuels production and use are employed to calculate the change in environmental externalities when substituting biofuels for petroleum fuels in Australia. These estimates of externalities highlight the need to better understand the environmental implications of biofuel production and use.

1 Introduction

Interest in biofuels as an alternative fuel source has grown in recent years and global biofuels production has increased rapidly, largely motivated by government support. Governments around the world have introduced biofuels support policies as a result of a number of considerations: climate change; air quality and human health; liquid fuels supply security; and, rural and regional industry growth. Despite the rapid increases in production, biofuels remain small contributors to global transport fuel supply, with a market share of around 2.8 per cent (IEA 2008). Biofuels currently comprise only 0.5 per cent of Australia's petrol and diesel supply. Australian fuel ethanol production is estimated at 112 million litres and biodiesel production at 59 million litres in 2007, compared with petrol sales of 19 320 million litres and diesel sales of 17 015 million litres (DRET 2008). Petrol and diesel represent around 70 per cent of the liquid fuels sold in Australia and are the direct competitors to biofuels.

ISSN: 1447-3666

Mandates and excise exemptions or subsidies are the most common form of biofuels support around the world. The two main forms of support for the Australian biofuels industry are a federal fuel excise tax exemption and a state consumption mandates in New South Wales. As in other countries, these policy measures do not distinguish between feedstocks used or production methods, despite significant differences in the environmental impacts of biofuels produced from different feedstocks. The environmental impacts of biofuels relate to greenhouse gas (GHG) emissions, air pollutant emissions, soil erosion, reduced biodiversity, and reduced water availability and quality. In this paper, estimates of GHG and air pollutant emissions from biofuels will be used to highlight the need to better understand the environmental implications of biofuel production and use.

An overview of current taxation arrangements for biofuels is provided in the following section. In section 3, the negative externalities associated with the production and use of biofuels are discussed. In section 4, the life-cycle emissions related to the use of ethanol and biodiesel are assessed against the life-cycle emissions associated with petroleum fuels. The externalities associated with biofuels from different feedstocks are then discussed in section 5. The final section includes concluding remarks.

2 Government policies

Australian government support for the biofuels industry includes fuel excise tax exemptions, capital grants, biofuels distribution grants and research and development grants. Currently, fuel excise tax is levied on petrol and diesel at the rate of 38.143 cents a litre. Biofuels such as ethanol and biodiesel are levied at this rate, but producers are eligible for production grants that effectively offset this excise tax. Biofuels are currently planned to remain effectively excise tax free until 1 July 2011, from when fuel excise tax will be applied. From 1 July 2011, liquid fuels will be reclassified into fuels of high, medium and low energy density, with different excise rates applied to each category. The effective rates of tax will increase annually until final excise tax rates are reached on 1 July 2015. In energy content terms, these final excise tax rates allow for a 50 per cent discount on the rates levied to petrol and diesel (ATO 2007).

After the changes to fuel tax policy have been implemented, and final tax rates are reached in July 2015, ethanol will receive an excise tax discount (equivalent to a subsidy) of 12.969 cents a litre relative to petrol (table 1), assuming the energy content of ethanol is 68 per cent that of petrol (Short and Riwoe 2005). Currently there is a limit of 10 per cent on the volume of ethanol content for petrol sold in Australia; this 10 per cent ethanol blend is known as E10 (DEWR 2007). The excise tax discount for E10 relative to petrol is 3.814 cents a litre. The final excise tax rates to be implemented in 2015 will be equivalent to a discount of 1.297 cents a litre for E10 relative to unleaded petrol (table 1).

1 Estimated subsidy (excise tax discount) equivalent rate for ethanol relative to petrol [a]

	2007 c/L	2015 c/L
Ethanol	38.143	12.969
E10	3.8143	1.297

a Based on data from ATO (2007).
Note: c/L refers to cents per litre. E10 is petrol with 10 per cent ethanol content.

Biodiesel is currently most commonly sold in a 5 per cent biodiesel and 95 per cent diesel blend, known as BD5. The excise tax discount for biodiesel is equivalent to a subsidy for BD5 of 1.907 cents a litre (table 2). Once the excise tax discount of 50 per cent relative to diesel in energy content terms is implemented in 2015, the tax rebates for BD5 could be between 0.858 cents a litre and 0.935 cents a litre, depending on the assumed energy content of biodiesel (table 2).

2 Estimated subsidy equivalent rate for biodiesel relative to diesel [a]

		2007 c/L	2015 c/L
Biodiesel	canola	38.143	17.164
	tallow	38.143	18.690
	waste oil	38.143	17.927
BD5	canola	1.907	0.858
	tallow	1.907	0.935
	waste oil	1.907	0.896

a Based on data from ATO 2007 and Short and Riwoe 2005.
Note: BD5 is a diesel blend containing 5 per cent biodiesel

3 Greenhouse gas emissions and air pollutants in Australia

The production and use of transport fuels generate negative externalities in the form of emissions of greenhouse gases (GHGs) and ambient air pollutants. The effects of emissions of GHGs such as carbon dioxide, methane and nitrous oxide, are not linked to the source of emissions; rather, it is the combined stock of GHG emissions in the atmosphere that has been associated with global temperature rises. In contrast, ambient air pollutants have direct effects near the source of emissions. Ambient air pollutants have been found to have adverse effects on human health and life expectancy. Illness caused by emissions and the associated impact on quality of life is referred to as the morbidity effect, while premature death because of emissions is the mortality effect (BTRE 2005).

Australia has relatively low levels of ambient air pollution. Pollutant emissions from motor vehicles fell significantly in the 1990s as catalytic converters became widespread and new fuel standards were implemented. Fuel quality standards have increased progressively since then. In 2008 the sulphur content in petrol and diesel was limited to 50 parts per million (AIP 2008). However, ambient air pollutant emissions still remain a concern. In 2000, pollution from motor vehicles is estimated to have caused between 900 and 4500 cases of morbidity and between 900 and 2000 cases of mortality (BTRE 2005).

Including both direct emissions from fuel combustion and the indirect emissions from fuel extraction, refining and fuel transport, the Australian road transport sector emitted 83 million tonnes of GHG in $C0_2$ equivalent terms ($C0_2$-e) in 2005-06 (ACG 2008). This represents around 14 per cent of Australia's total GHG emissions (DCC 2008). The road transport sector's direct and indirect emissions of particulate matter and nitrogen oxide were 18 923 tonnes and 501 270 tonnes, respectively. Passenger vehicles are the largest contributor to road transport emissions. In 2005-06, passenger vehicles represented 59 per cent of GHG emissions from the road transport sector. Passenger vehicles are also a significant contributor to ambient air pollution, accounting for 50 per cent of nitrogen oxide emissions and 36 per cent of particulate matter emissions from the road transport sector in 2005-06. Trucks are the second largest contributor to emissions from road transport, accounting for 22 per cent of GHG, 36 per cent of particulate matter and 27 per cent of nitrogen oxide emitted by the road transport sector in 2005-06 (ACG 2008).

4 Environmental externalities from biofuels and petroleum fuels

A market failure can arise in the transport fuels market if the potential differences in emissions from petroleum based fuels and those from biofuels are not taken into account in the decisions of fuel producers and consumers. To ensure economic efficiency is achieved the costs of these emissions, in the form of climate change and human health effects, must be reflected in the tax-inclusive price of the different fuels. Policy intervention through an emissions tax or a subsidy for avoided emissions could be justified to address this market failure. This paper will illustrate how estimates of environmental externalities from biofuels may be reflected in the difference in price between petroleum based fuels and biofuels.

In the following two sections, life-cycle estimates of ambient air pollution and GHG emissions arising from biofuels production and use are compared with those arising from petrol and diesel production and use. There have been an increasing number of international studies of life-cycle GHG emissions from biofuels in recent years.

Studies that consider air pollutants are less common and few have been carried out for Australian conditions. An assessment of existing estimates of life-cycle emissions of both GHGs and air pollutants from biofuels was undertaken in a 2003 report for the Australian Government Department of Industry Tourism and Resources (CSIRO, BTRE, ABARE 2003), which examined the implications of implementing a 350 million litres target for biofuels production. This study was reviewed and updated in the 2005 Biofuels Taskforce Report (Australian Government 2005). A review of Australian and international estimates of life-cycle emissions from biofuels was undertaken in both studies in order to produce a synthesised set of estimates that were considered to be most relevant to Australian conditions. These estimates take into account direct emissions from vehicles and emissions from fuel extraction, production (including production of by-products), transport, processing, conversion and distribution. Emissions estimates from the two studies have been used to calculate the life-cycle externalities in terms of emissions associated with each type of fuel. However, it is important to note that the emissions estimates can vary because of the variations in the biofuels production methods used by individual production facilities. Therefore, emissions estimates discussed in this paper should only be taken as indicative values for the purpose of illustrating the differences between fuels.

Ethanol

Air pollutants

Life-cycle air pollutant emissions from E10 and unleaded petrol used in a standard passenger car are shown in table 3. The emissions estimates are shown for the five ethanol production feedstocks currently used in Australia:

- molasses using bagasse to generate the electricity used in the ethanol production process;
- molasses using non-renewable electricity;
- grain sorghum;
- wheat; and
- waste wheat starch that is a residue from flour production.

Life-cycle air pollutant emissions vary according to the feedstock used for ethanol production. This is because of the differences in the upstream ethanol production process. Tailpipe emissions from the use of E10 do not vary by feedstocks, although they do depend on other factors related to the type of vehicle used and driving patterns (CSIRO, BTRE, ABARE 2003; Australian Government 2005). Emissions estimates are presented in table 3 for a standard passenger car, which is assumed to be the same for each fuel. In practice, some ethanol producers may use a combination of feedstocks according to seasonal availability and price. However, since the quantities of each feedstock that may be used to produce an ethanol blend are not known, it is assumed in this paper that each production plant uses only one feedstock to produce ethanol.

The most significant difference between air pollutant emissions from E10 and petrol lies in particulate matter (PM) emissions. Tailpipe emissions of PM from E10 are 40 per cent lower than emissions from petrol. However at the upstream production process (in both urban and non-urban areas), PM emissions from E10 are between 81 and 99 per cent higher than emissions from petrol, except in the case of ethanol produced from molasses using co-generation technology, which has lower PM emissions than petrol (11 per cent).

At the tailpipe, emissions of carbon monoxide (CO) from E10 are 27 per cent lower than emissions from unleaded petrol (table 3). Emissions of volatile organic compounds (VOC) from E10 are 14 per cent lower than from unleaded petrol at the tailpipe, while nitrogen oxide (NO_x) emissions are 5 per cent higher. The quantity of CO emitted during the upstream production process of E10 is higher than emissions from the production of petrol, although the magnitude of this difference varies greatly depending on the feedstock used to produce the ethanol component of E10; from 11 to 13 per cent for ethanol produced from grain sorghum or wheat starch waste, to 218 to 301 per cent for ethanol produced from molasses or wheat. Upstream VOC emissions are higher for E10 than for petrol. This increase in emissions relative to petrol is most significant when ethanol is produced from wheat and lowest if it is produced from wheat starch waste. The difference in emissions of NO_x at the upstream stage when substituting E10 for petrol, ranges from a decrease of 1.4 per cent, if the ethanol is produced from molasses using cogeneration, to an increase of 13 per cent when the ethanol is produced from wheat.

The estimated percentage changes in emissions when substituting ethanol for unleaded petrol that are presented in table 3 can be translated into a change in emissions for each litre of fuel used. In calculating the

3 Percentage difference per km travelled in full life-cycle air pollutants between E10 and unleaded petrol (ULP)

air pollutants	E10 (ULP) (molasses cogen energy) %	E10 (ULP) (molasses) %	E10 (ULP) (grain sorghum) %	E10 (ULP) (wheat) %	E10 (ULP) (wheat starch waste) %	ULP g/km
CO (Tailpipe)	–26.866	–26.866	–26.866	–26.866	–26.866	4.850
CO (Upstream)	218.282	217.950	11.222	301.173	12.992	0.090
NO_x (Tailpipe)	5.028	5.028	5.028	5.028	5.028	0.461
NO_x (Upstream)	–1.437	4.561	1.354	13.078	0.666	0.480
VOC (Tailpipe)	–14.362	–14.362	–14.362	–14.362	–14.362	0.168
VOC (Upstream)	2.107	1.823	1.659	4.558	1.599	0.669
PM (Tailpipe)	–40.000	–40.000	–40.000	–40.000	–40.000	3.346
PM (Upstream–urban)	–5.239	86.774	97.678	97.253	94.704	7.062
PM (Upstream–non–urban)	–5.603	–5.845	–15.251	1.545	–9.205	7.442

Sources: CSIRO, BTRE, ABARE 2003; Australian Government 2005.
Notes: CO is carbon monoxide, NO_x is nitrogen oxide, VOC is volatile organic compounds, PM is particulate matter.

estimated difference in life-cycle emissions between ethanol and unleaded petrol presented in table 4, the energy requirements of a passenger car have been assumed to be 4.63 megajoules per litre and the energy density of ethanol has been assumed to be 21 megajoules per litre (Australian Government 2005).

4 Estimated difference per litre in full life-cycle air pollutants between E10 and ULP (passenger car)

air pollutants	E10 (ULP) (molasses cogen energy) g/L	E10 (ULP) (molasses) g/L	E10 (ULP) (grain sorghum) g/L	E10 (ULP) (wheat) g/L	E10 (ULP) (wheat starch waste) g/L
CO (Tailpipe)	–5.910	–5.910	–5.910	–5.910	–5.910
CO (Upstream)	0.895	0.893	0.046	1.234	0.053
NO_x (Tailpipe)	0.105	0.105	0.105	0.105	0.105
NO_x (Upstream)	–0.031	0.099	0.029	0.285	0.015
VOC (Tailpipe)	–0.109	–0.109	–0.109	–0.109	–0.109
VOC (Upstream)	0.064	0.055	0.050	0.138	0.049
PM (Tailpipe)	–6.070	–6.070	–6.070	–6.070	–6.070
PM (Upstream–urban)	–1.678	27.794	31.287	31.151	30.334
PM (Upstream–non–urban)	–1.891	–1.973	–5.148	0.522	–3.107

Note: The energy requirements of a passenger car are assumed to be 4.63 megajoules per litre and the energy density of ethanol is assumed to be 21 megajoules per litre.

To obtain a comparison of the effects of different types of air pollutant emissions, values must be assigned to each unit of emissions. CSIRO, BTRE, ABARE (2003) and Australian Government (2005) provided health cost estimates calculated by Watkiss (2002). The Watkiss estimates were selected as they were derived for Australian conditions, they provide health costs which vary by population density and type of pollutant, and they incorporate long-term health effects.

The effect of air pollutants on mortality and morbidity increases as the pollutants become more concentrated (CSIRO, BTRE, ABARE 2003). The cost of these effects depends on the values assigned to the loss of life and the quality of life, in addition to the costs incurred through the use of the health system. Values for loss of life and quality of life generally vary considerably and are influenced by ethical viewpoints. However, these values are necessary to compare the effect of different pollutants and are used here solely to evaluate the substitution of different fuels, rather than to provide an estimate of the absolute health effect of each fuel. Estimates of health costs associated with different types of air pollutants for Australian conditions are shown in table 5. The greatest health costs are incurred in the central areas of large cities, where the population is highly concentrated. Rural areas incur the lowest health costs associated with ambient air pollutants (table 5). These can be regarded as the maximum and minimum health costs estimates, with costs falling as the population density decreases.

The health cost estimates presented in table 5 can be combined with the estimates of emissions per litre of ethanol shown in table 4 to estimate the cost of air pollutant emissions associated with each litre of E10, compared to the health costs arising from petrol use. For this purpose, ethanol production plants are assumed to be located in rural areas where grains or sugar cane is cultivated, while E10 fuel is assumed to be consumed in the inner areas of large cities. In practice, E10 will be consumed in urban and non-urban areas with varying levels of population density. Thus, the estimates of health costs associated with the use of E10 presented in this section should be regarded as an upper estimate.

5 Unit health costs of ambient air pollutants in Australia

	inner large city	outer large city	non-urban
Pollutant	$/t	$/t	$/t
CO	2.3	1.5	0.3
NO_x	1 253.3	756.7	86.7
VOC	643.3	411.7	60.0
PM	258 827.0	176 003.0	31 887.0

Sources: CSIRO, BTRE, ABARE 2003; Australian Government 2005

The substitution of E10 for unleaded petrol results in higher health costs associated with ambient air emissions, except in the case where ethanol is produced from molasses using cogeneration (table 6). The health costs associated with E10 production and use are lowest for ethanol produced from molasses and highest for ethanol produced from wheat. The cost of ambient air emissions are primarily driven by upstream emissions of PM, which are significantly higher for E10 than petrol, except when the ethanol is produced from molasses. The effect of PM emissions on health is also much higher than the health effect of other pollutants.

These net air pollution emissions represent an externality associated with the substitution of E10 for petrol. For example, when substituting E10 made from grain sorghum for petrol, increased air pollutant emissions are estimated to have a cost of 0.38 cents per litre of E10 (table 6).

6 Estimated difference in costs of externalities between E10 and ULP

	molasses cogen	molasses	grain sorghum	wheat	wheat starch waste
	c/L	c/L	c/L	c/L	c/L
Ambient air pollutants	–0.188	0.332	0.382	0.401	0.372
Greenhouse gas emissions	–0.386	–0.248	–0.184	–0.064	–0.248
Total externalities	–0.573	0.084	0.199	0.337	0.124

Note: The price of a tonne of carbon is assumed to be $A50, based on the highest price for European emissions permits since 2006. Negative values indicate a decrease in externalities when substituting ethanol for unleaded petrol.

Greenhouse gas emissions

The production of ethanol, including the production of feedstocks used, has been found to require more energy than the production of petrol for each unit of fuel produced. This results in greater GHG emissions at the upstream level (in $C0_2$-e terms). However, the combustion of ethanol emits less greenhouse gas emissions than the combustion of petrol. The net effect is a reduction in greenhouse gas emissions over the full life-cycle of the fuels, when substituting ethanol for petrol (CSIRO, BTRE, ABARE 2003; Australian Government 2005). Ethanol made from wheat generates the lowest reduction in GHG emissions, while the greatest reduction is achieved with ethanol made from molasses using cogeneration. For E10 these savings in emissions per kilometre travelled vary from a reduction of 0.7 per cent when ethanol is made from wheat, to a 4.2 per cent emissions saving when ethanol is made from molasses using bagasse cogeneration (table 7).

FAO (2008) estimated the maximum GHG emissions reductions which could be obtained from biofuels produced from conventional feedstocks to be in the range of 20 to 60 per cent for each unit of output (2 to 6 per cent for a 10 per cent biofuel blend). A 2007 OECD study (Doornbosch and Steenblik, 2007) found life-cycle GHG emissions reductions between 25 and 82 per cent for each unit of output for biofuels produced from the currently most common feedstocks. However, studies which have focused on the land use change effects of biofuels have generally found biofuels to emit more GHGs than petroleum fuels over their full life-

7 Difference in greenhouse gas emissions between E10 and ULP

	ULP g/km	molasses cogen %	molasses %	grain sorghum %	wheat %	wheat starch waste %
CO_2-e	404.98	–4.2	–2.7	–2.0	–0.7	–2.7

Sources: CSIRO, BTRE, ABARE 2003; Australian Government 2005.

cycle. One such study, Fargione et al. (2008), estimated the conversion of rainforests, peatlands, savannahs or grasslands to produce biofuels in Brazil, Indonesia, Malaysia or the United States releases 17 to 420 times more carbon dioxide than the annual GHG reductions that result from substituting these biofuels for fossil fuels.

The cost of restricting emissions to a particular level can be represented by the price of tradeable emissions permits under a cap and trade system. Currently there is no global emissions permit system that would provide an estimate of the cost of stabilising global emissions at some level. The proposed Carbon Pollution Reduction Scheme in Australia will establish a GHG emissions cost when implemented. Biofuels are currently proposed to be initially excluded from the scheme, while petroleum fuels will initially receive a rebate to offset the carbon price. The European Union emissions permit trading scheme is the world's largest carbon trading system. Emissions permit prices were between 15 and 19 euros (A$30 – $A38) a tonne in November 2008 (Point Carbon 2008). The highest price for European Union tradable emissions permits since 2006 has been around $50 a tonne. As there is currently no established GHG emission unit cost in Australia, the approach taken in this paper is to calculate possible GHG emissions costs under a range of illustrative carbon prices (table 8).

Under carbon prices from $10 to $500 a tonne of $C0_2$-e, the net benefit from avoided greenhouse gas emissions when substituting E10 for petrol would range from 0.01 cents a litre to 3.86 cents a litre, with the highest benefit arising from ethanol produced from molasses using cogeneration and the lowest benefit arising from ethanol produced from wheat (table 8).

8 Estimated difference in greenhouse gas emissions costs between E10 and ULP

carbon price $/t CO_2-e	molasses cogen c/L	molasses c/L	grain sorghum c/L	wheat c/L	wheat starch waste c/L
10	–0.077	–0.050	–0.037	–0.013	–0.050
15	–0.116	–0.074	–0.055	–0.019	–0.074
20	–0.154	–0.099	–0.073	–0.026	–0.099
30	–0.231	–0.149	–0.110	–0.039	–0.149
50	–0.386	–0.248	–0.184	–0.064	–0.248
100	–0.771	–0.496	–0.367	–0.129	–0.496
500	–3.857	–2.480	–1.837	–0.643	–2.480

Biodiesel

Air pollutants

As in the ethanol analysis above, the analysis of the environmental performance of biodiesel assumes each production plant uses only one feedstock. In practice, biodiesel producers are likely to use a combination of feedstocks. When using tallow (animal fat) as a feedstock, for example, producers will need to combine this with other feedstocks, such as canola oil, to avoid solidification of the biodiesel at lower temperatures. Biodiesel production plants using waste cooking oil as their feedstock are assumed to be located on the outer areas of large cities, where there is greater availability of used cooking oil. Biodiesel plants using canola or tallow are assumed to be located in rural areas, where these feedstocks are readily available. The consumption of biodiesel blended fuel is assumed to occur in the inner areas of large cities.

In this section, life-cycle emissions from a blend of 5 per cent biodiesel and 95 per cent ultra low sulphur (ULS) diesel are compared with emissions from ULS diesel used in rigid trucks. ULS diesel has a sulphur content of 50 parts per million (ppm), which is the maximum sulphur content permitted in diesel since January 2006 (DEWR 2007b).

At the tailpipe, emissions of CO, VOC and PM are lower from a 5 per cent biodiesel blend (BD5) than from ULS diesel, but emissions of NO_x are higher (table 9). Emissions of CO from the upstream production process are higher for BD5 than for ULS diesel when biodiesel is made from canola or tallow, but lower than ULS diesel when the biodiesel is made from waste cooking oil. Emissions of particulates during the upstream production process of BD5 range from being 0.7 per cent higher to 4.4 per cent lower than ULS diesel, depending on the feedstock. Upstream emissions of NO_x from BD5 are higher than emissions from ULS diesel when the biodiesel is produced from canola or tallow, but lower when the biodiesel is produced from waste cooking oil (table 9).

Using the estimates presented in tables 5 and 10, the health costs associated with emissions from BD5 produced from canola are estimated to be 0.27 cents a litre lower than the health costs that arise from the production and use of ULS diesel. The avoided health costs when BD5 is substituted for ULS diesel are

9 Estimated percentage difference in full life-cycle air pollutants between BD5 and ultra low sulphur (ULS) diesel (rigid truck)

air pollutants	BD5 biodiesel (canola & ULS) %	biodiesel BD5 (tallow & ULS) %	biodiesel BD5 (waste oil & ULS) %	full life-cycle air pollutants from ULS diesel g/km
CO (Tailpipe)	–15.702	–15.702	–15.702	3.267
CO (Upstream)	7.869	3.580	–1.023	0.352
NO_x (Tailpipe)	6.795	6.795	6.795	10.890
NO_x (Upstream)	3.223	2.609	–2.072	1.303
VOC (Tailpipe)	–12.331	–12.331	–12.331	0.908
VOC (Upstream)	–0.312	–0.687	–2.726	0.481
PM (Tailpipe)	–2.096	–2.096	–2.096	338.800
PM (Upstream–urban)	0.668	0.668	–2.671	17.970
PM (Upstream–non–urban)	–0.597	–0.836	–4.418	16.750

Sources: Calculations based on data from CSIRO, BTRE, ABARE 2003; Australian Government 2005.

estimated to be 0.30 cents per litre when biodiesel is produced from tallow and 0.33 cents per litre when biodiesel is produced from waste cooking oil (table 11).

Greenhouse gas emissions

Biodiesel emits less GHG emissions over its life-cycle, each kilometre travelled, than ethanol. When a 5 per cent biodiesel blend is substituted for ultra low sulphur diesel, greenhouse gas emissions per kilometre travelled are 4.2 per cent lower if the biodiesel is made from waste cooking oil and 1.5 per cent lower if the biodiesel is made from tallow or canola (table 12).

Under a carbon price of $A50 a tonne of C0$_2$-e, the costs avoided as a result of these emissions reductions range from 0.21 cents a litre to 0.62 cents a litre (table 13). If the price of carbon were to rise to $A200 a tonne of C0$_2$-e, the avoided costs from emissions reductions would range from 0.85 cents a litre (if the biodiesel is made from canola) to $A2.48 a litre (if the biodiesel is made from waste oil).

10 Estimated difference per litre in full life-cycle air pollutants between BD5 and ULS diesel (rigid truck)

air pollutants	biodiesel BD5 (canola & ULS) g/L	biodiesel BD5 (tallow & ULS) g/L	biodiesel BD5 (waste cooking oil & ULS) g/L
CO (Tailpipe)	–1.455	–1.584	–1.521
CO (Upstream)	0.079	0.039	–0.011
NO$_x$ (Tailpipe)	2.098	2.285	2.193
NO$_x$ (Upstream)	0.119	0.105	–0.080
VOC (Tailpipe)	–0.317	–0.346	–0.332
VOC (Upstream)	–0.004	–0.010	–0.039
PM (Tailpipe)	–20.134	–21.926	–21.045
PM (Upstream–urban)	0.340	0.371	–1.423
PM (Upstream–non–urban)	–0.284	–0.432	–2.193

Note: The energy requirements of a rigid truck are assumed to be 12.24 megajoules per kilometre (Australian Government 2005). The energy density of biodiesel made from canola is assumed to be 34.7 megajoules per litre, the energy density of biodiesel made from tallow is assumed to be 37.8 megajoules per litre and the energy density of biodiesel made from waste cooking oil is assumed to be 36.3 megajoules per litre (Short and Riwoe 2005)

11 Estimated difference in costs of externalities between BD5 and ULS diesel

	canola c/L	tallow c/L	waste cooking oil c/L
Ambient air pollutants	–0.273	–0.298	–0.331
Greenhouse gas emissions	–0.213	–0.231	–0.619
Total externalities	–0.485	–0.529	–0.950

Note: The price of a tonne of carbon is assumed to be $A50, based on the highest price for European emissions permits since 2006.

12 Difference in greenhouse gas emissions between BD5 and ULS diesel

	ULS diesel g/km	canola %	tallow %	waste cooking oil %
CO$_2$-e	999.2378	–1.5	–1.5	–4.18

Sources: Calculations based on data from CSIRO, BTRE, ABARE 2003 and Australian Government 2005.

13 Difference in greenhouse gas emissions costs between BD5 and ULS diesel

carbon price $/t	canola c/L	tallow c/L	waste cooking oil c/L
10	–0.04	–0.05	–0.12
20	–0.09	–0.09	–0.25
30	–0.13	–0.14	–0.37
50	–0.21	–0.23	–0.62
100	–0.43	–0.46	–1.24
200	–0.85	–0.93	–2.48
500	–2.13	–2.31	-6.19

5 Cost of externalities and relative prices of fuels

The differences in costs associated with both ambient air pollutants and GHG emissions from biofuels and petroleum fuels can be combined to determine the total external cost or benefit from substituting biofuels for petroleum fuels. In this analysis it is assumed that the cost of carbon is $A50 a tonne, as represented by the highest price for European Union tradable emissions permits since 2006.

The substitution of E10 for petrol imposes a net emissions cost, unless the ethanol component in E10 is produced from molasses using cogeneration technology (table 6). Hence, it could be argued that, from an economic perspective, in order to internalise the emissions costs or benefits from ethanol production, the price of E10 relative to petrol would need to be changed. The tax or subsidy equivalent of environmental costs or benefits associated with E10 could vary depending on the feedstock used for ethanol production. For example, for ethanol produced from molasses using cogeneration, a subsidy equivalent of 0.57 cents a litre of E10 would reflect the estimated net benefits of substituting E10 for petrol. However, for ethanol produced from any of the other four feedstocks, the estimated net emissions cost of substituting E10 for petrol would be reflected by a tax equivalent on E10 of between 0.08 and 0.34 cents a litre higher than the fuel excise tax on petrol.

In contrast to ethanol, the substitution of BD5 for ULS diesel results in a net benefit in terms of emissions reductions. The combination of lower health costs associated with air pollutants and lower GHG emissions when BD5 is substituted for ULS diesel are estimated to result in a net benefit over the fuels' life-cycle of between 0.49 and 0.95 cents per litre (table 11), with the lowest benefit arising from biodiesel produced from canola oil.

The analysis shows there is not a large difference in the life-cycle emissions per unit of output from biodiesel produced from different feedstocks and, more importantly, all the feedstocks currently used in Australia are estimated to provide a reduction in emissions over the fuel's life-cycle. In addition, the emissions from biodiesel produced from canola or tallow are comparable with the emissions from ethanol produced from molasses using co-generation; and the emissions from biodiesel produced from used cooking oil are lower than those from ethanol produced from molasses using co-generation. Such information can be used to determine the subsidy equivalent that would reflect the externalities associated with different biofuels.

6 Conclusion

GHG emissions, air pollution, and other issues associated with Australia's dependence on petroleum-based fuels will continue to drive the search for alternative fuel sources. From an economic perspective, any support for biofuels and other alternatives should reflect the magnitude of their relative benefits (in terms of externalities) over petroleum fuels.

Research in preparing this paper has found that air pollutants and GHG emissions from biofuels will vary greatly according to the feedstocks from which they are produced. Generally, the production and use of biodiesel has less external costs than ethanol. The substitution of ethanol for petrol results in a net increase in emissions, unless ethanol is produced from molasses using cogeneration. Conversely, the substitution of biodiesel for diesel results in a net emissions reduction, regardless of the feedstock used. Economic efficiency would require a distinction between different biofuels production methods in order to account for the differences in emissions.

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