

7. Diesohol

7.1 Background

Diesohol is a fuel containing alcohol that comprises a blend of diesel fuel (84.5%), hydrated ethanol (15%) and an Australian developed emulsifier (0.5%). Hydrated ethanol is ethyl alcohol that contains approximately 5% water. The emulsifier is an important component in the preparation of the fuel. It has been developed in Australia by APACE Research.

Development and use of alcohol fuels in transport have, for the most part, been driven by the desire in many countries to find substitutes for imported petroleum based fuels. Alcohol fuels have also been used as additives to conventional fuels to improve fuel characteristics. More recently they have been the focus of attention as a possible means of reducing greenhouse gas emissions and noxious urban emissions from transport.

Anhydrous ethanol will readily blend with petrol. Hydrated ethanol containing more than 2% v/v water is not completely miscible with petrol. Hydrated ethanol is not miscible with diesel but can form an emulsion using a suitable emulsifier. Alcohols can be used in diesel engines by either modifying the fuel or by extensive engine adaptations. Work in Australia by APACE Research Ltd has produced an ethanol and diesel emulsion called 'diesohol'. APACE claims that a diesohol emulsion containing up to 30 per cent ethanol will run in a diesel engine, with the engine requiring little or no modification. The ACTION bus fleet in Canberra trialed three new buses running on diesohol (Scott et al., 1995; Joseph, 1996). Sydney Buses also used such buses from 1993 to 1998 (Figure 7.1).



Figure 7.1
Diesohol bus used by Sydney Buses from 1993 to 1998.

7.2 Characteristics of Diesohol

Table 7.1 lists some of the physical properties of diesohol prepared from regular diesel and from low sulfur diesel.

Table 7.1
Diesohol fuel quality specifications (APACE Research Ltd, 1999)

Fuel parameter	Regular Diesohol	Low Sulfur Diesohol
Sulfur (ppm)	1000	300
Density at 15°C (kg/m ³)	846.5	846.5
Distillation T95 (°C)	336.4	330.7
Calculated cetane index	52	52
Ash & suspended solids (ppm)	100	100
Viscosity (mm ² /s)	3.568	3.256
Water content (mg/L)	8860	10551
Hydrogen content (mass %)	13.7	12.8
Carbon content (mass %)	86.2	87.2

The lower calorific value of ethanol is 20.6 MJ/L (25.6MJ/kg), which drops to 19.41 MJ/L (23.96 MJ/kg) when hydrated 5% v/v with water. Thus the lower calorific value of a blend of 15% hydrated ethanol with diesel (which has a lower calorific value of 35.70 MJ/L or 42.75 MJ/kg) is 33.26 MJ/L. According to APACE Research Ltd. the thermodynamic cycle is affected by the extended ignition delay due to the alcohol. This tends to increase the thermal efficiency, especially under full load conditions. The power reduction is thus less than calculated from calorific values alone. For example, use of 15% v/v ethanol emulsion is calculated to result in a 7.3% reduction in power. However, a reduction of only 3-4 % is usually obtained in practice.

7.3 Production and Distribution

Because ethanol comprises only 15% of diesohol, this section briefly reviews the upstream processes associated with ethanol production. Greater detail is given in the previous examination of ethanol as a fuel in its own right.

7.3.1 Ethanol production

At present there are only two sources of ethanol in Australia. It is manufactured from biomass via the fermentation of sugar that is derived either from wheat starch or from molasses. Starch and sugar crops in Australia that have received attention as a potential source of ethanol include cassava in Queensland; sugarcane in Queensland and northern NSW; sweet sorghum in Queensland, NSW and Victoria; Jerusalem artichokes and potatoes in Victoria; sugar beet in Victoria and Tasmania; and cereals in NSW and Victoria. In Sweden, much of the ethanol used as a fuel comes from excess European wine production (Ericson and Odehn, 1999).

7.3.2 Ethanol from sugar

Ethanol has traditionally been produced in Australia from molasses, a by-product of the sugarcane industry. CSR supplies around half of the Australian ethanol market with an annual plant capacity of 55 million litres (www.csr.com.au/about/Facts_Distilling.htm).

Production of ethanol from molasses constitutes part of the sugar refining process. The overall process consists of the following main steps:

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1. **Crushing** : Sugar cane “as farmed” is chopped at the sugar mill to facilitate handling and processing.
2. **Sugar extraction** : This is effected in a countercurrent flow of warm water. The solids after extraction (bagasse) containing less than 0.5% sugar are squeeze-dried to remove maximum of sugar solution (liquor). Dry bagasse is used as fuel to power sugar mill operation.
3. **Raw sugar production** : Sugar-containing liquor is concentrated in evaporators. Crystalline sugar is separated in centrifuges. This process is repeated several times yielding raw sugar. It may be further refined if necessary.
4. **Fermentation of molasses** : Liquid residue from sugar production (molasses) containing approximately 50% sugar and 50% mineral matter is mixed with yeast and fermented yielding 6 to 7% ethanol. Solid residue after fermentation (dunder) contains mostly yeast and minerals and is used as fertiliser. Yeast is sometimes separated and used by the food industry.
5. **Distillation**: The fermented mash, now called "beer," contains about 10% alcohol, as well as all the non-fermentable solids from the sugar and the yeast cells. The mash is pumped to the continuous flow, multi-column distillation system where the alcohol is removed from the solids and the water. The alcohol leaves the top of the final column at about 96% strength, and the residue mash, called stillage, is transferred from the base of the column to the co-product processing area.
6. **Dehydration**: The alcohol from the top of the column then passes through a dehydration system where the remaining water is removed. Most ethanol plants use a molecular sieve to capture the last drop of water in the ethanol. The alcohol product at this stage is called anhydrous (pure, without water) ethanol and is approximately 200 proof.
7. **Denaturing**: Ethanol that will be used for fuel is then denatured with a small amount (0-5%) of some product, such as gasoline, to make it unfit for human consumption.

APACE Research (R. Reeves, pers, comm.) notes that molasses is the residue from the production of crystal sugar for food. As residue it has a lower (though non-zero) economic value than the primary output. In the case of CSR’s azeotropic ethanol-from-molasses plant at Sarina in Queensland, the processing energy input is supplied from combustion of the sugar cane bagasse. Surplus bagasse is also used by CSR for electrical power cogeneration.

7.3.3 Ethanol from starch

Ethanol is also produced from wheat at Manildra’s gluten and starch plant at Nowra, Figure 7.2. The major products of the mill are gluten and starch. The ethanol produced from the waste starch stream with further supplementations of starch is essentially a by-product of the gluten manufacturing process.

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Figure 7.2
The ethanol plant at Manildra's Nowra plant.
(<http://www.manildra.com.au/prospectus/prospectus6.html>)

There are basically eight steps in the ethanol production process from wheat starch:

1. **Milling:** The wheat (or corn, barley, etc.) first passes through hammer mills, which grind it into a fine powder called meal.
2. **Liquefaction:** The meal is then mixed with water and alpha-amylase, and passes through cookers where the starch is liquefied. Heat is applied at this stage to enable liquefaction. Cookers with a high temperature stage (120-150°C) and a lower temperature holding-period (90°C) are used. These high temperatures reduce bacteria levels in the mash.
3. **Saccharification:** The mash from the cookers is then cooled and the secondary enzyme (gluco-amylase) added to convert the liquefied starch to fermentable sugars (dextrose), a process called saccharification.
4. **Fermentation:** Yeast is then added to the mash to ferment the sugars to ethanol and carbon dioxide. This carbon dioxide, being completely renewable in origin, is not included in the calculations. Using a continuous process, the fermenting mash flows, or cascades, through several fermenters until the mash is fully fermented and then leaves the final tank. In a batch fermentation process, the mash stays in one fermenter for about 48 hours before the distillation process is started.
5. **Distillation:** The fermented mash, now called "beer," contains about 10% alcohol, as well as all the non-fermentable solids from the wheat and the yeast cells. The mash is then pumped to the continuous flow, multi-column distillation system where the alcohol is removed from the solids and the water. The alcohol leaves the top of the final column at about 96% strength, and the residue mash, called stillage, is transferred from the base of the column to the co-product processing area.
6. **Dehydration:** The alcohol from the top of the column then passes through a dehydration system where the remaining water is removed. Most ethanol plants use a molecular sieve to capture the last drop of water in the ethanol. The alcohol product at this stage is called anhydrous (pure, without water) ethanol and is approximately 200 proof.
7. **Denaturing:** Ethanol for fuel is then denatured with a small amount (0-5%) of some product, such as gasoline, to make it unfit for human consumption.
8. **Co-Products:** There are two main co-products created in the production of ethanol: carbon dioxide and distillers grain. Carbon dioxide is given off in great quantities during

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fermentation and many ethanol plants collect that carbon dioxide, clean it of any residual alcohol, compress it and sell it for use to carbonate beverages or in the flash freezing of meat. This carbon dioxide, also being completely renewable in origin, is not included in the calculations. Distillers grains, wet and dried, are high in protein and other nutrients and are a highly valued livestock feed ingredient. Some ethanol plants also create a "syrup" containing some of the solids that can be a separate production sold in addition to the distiller's grain, or combined with it. Manildra uses this process to produce fructose.

Energy and emission data for ethanol production are available from a number of sources including a NREL study (Kadam et al., 1999) and from Swedish data published on the BioAlcohol Fuels Website (Bioalcohol Fuel Foundation, 2000). These data sources look at different processes (from acid to enzyme) and different feedstocks including woodwaste and straw. However, given the nature of diesohol as a proprietary fuel blend being produced at a specific plant from specific feedstocks, data on ethanol for diesohol production has been taken from documents and personal communications with APACE Research (R. Reeves, pers. comm.). They point out that modern, integrated ethanol-from starch plants, such as that of Manildra, have a processing energy input of approximately 4.5 MJ/L of azeotropic ethanol, and 5.9 MJ/L of anhydrous ethanol. Based on a lower calorific value of 19.43 MJ/L for azeotropic ethanol and 21.15 MJ/L for anhydrous ethanol, and assuming natural gas to steam conversion efficiency of 70%, Reeves estimates the processing energy input to be 0.33 of the lower calorific value for ethanol for azeotropic ethanol, and 0.40 for anhydrous ethanol (as described in Appendix 6).

No individual process data is available for the Manildra process so it has been modelled as a black box with waste product and coal based heat into the plant, with ethanol as the main output. The ethanol was assumed to be azeotropic so the energy use of ethanol production was 9 MJ/L (as in Table 6.10 in the chapter on hydrated ethanol).

There are no solid residues available for combustion from Manildra's ethanol-from-starch plant. All liquid effluent streams, principally the underflow from the stripping distillation column, are irrigated onto surrounding land for intensive pasture production. Thus the liquid effluent has displaced use of conventional fertilisers and significantly increased the soil carbon content. Given that the source of carbon is from renewable sources, no credit for fixing fossil carbon is given from a greenhouse perspective. For the same reason carbon dioxide emissions from fermentation are not included as greenhouse impacts as they are from short-term carbon cycles.

Without clear estimates of the nutrient replacement achieved through land application of effluents, and evidence of this lowering fertiliser use, it is not possible to provide credits for avoided fertiliser use. The effect of these credits is thought to be small in any case.

It is assumed that the starch feedstock used by Manildra for ethanol production is waste starch from Manildra's gluten production, or is derived from reject grain. Because of the low value of these feedstocks, they are treated as waste products and not as by-products of the starch process, and thus have no environmental burdens associated with them. If the value of these feedstocks increase, or higher grade grain is used in the Manildra plant, then an alternative allocation will be needed to include environmental burdens of the feedstock. Modelling of ethanol, as for fuels other than diesohol, included in the next stage of the report, will include allocation procedures for production from dedicated feedstocks and valuable by-products.

Emulsifier for diesohol

According to APACE research the emulsifier that allows the ethanol and the diesel to blend consists of a styrene-butadiene copolymer which is dissolved in the diesel fuel, and a polyethyleneoxide-polystyrene (PEOPS) copolymer which is dissolved in the hydrated alcohol. No values are known as to the proportions of these substances so a total emulsifier is assumed to consist of 50% of each co-polymer. The co-polymers are then also assumed to

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consist of 50% of the two polymer constituents. The resultant mixture for the emulsifier is shown in Table 7.2

Table 7.2
Data summary for 1kg of emulsifier used in diesohol

Component	Amount Assumed	Inventory data source
Styrene	250 g	Steinhage (1990) modified with Australian feedstocks
Butadiene	250 g	Steinhage (1990) & Reinders (1983) modified with Australian feedstocks
Polyethylene Oxide	250 g	Grant (1999) as polyethylene
Polystyrene	250 g	Same as for Styrene with polymerisation data from Steinhage (1990)

7.4 Diesohol Emissions

7.4.1 Upstream

Hydrated (or azeotropic) ethanol derived from sugar, or ethanol derived from wheat starch, may be used for production of diesohol. Hydrated ethanol production is a one-stage refining process, unlike the two-stage anhydrous ethanol. However, from the viewpoint of the LCA, the upstream emissions for ethanol production will be different for both processes.

There are two reasons for this. First, there are differences in energy demand for both processes. Second, as in both cases ethanol is a co-produced with other value added products, there will be differences in emissions allocation as per ISO 14040.

In the past, the ethanol used for diesohol came from the Manildra refinery. The calculations in this report are based on the present source of ethanol for diesohol, namely the CSR refinery at Sarina.

7.4.2 Tailpipe

APACE Research (Ernie Lom, pers. comm.) provided results from Swedish tests of diesohol conducted in 1997¹. These results (Table 7.3) are for fuels that blend diesohol with Swedish Diesel fuel and with European diesel (EDsl) meeting EN590 specifications. European diesel is a low-sulfur fuel. Swedish diesel is an ultra-low sulfur fuel.

Table 7.3
Results of Swedish tests of diesohol (g/MJ) with low sulfur (ED) and ultra-low sulfur (SwD) fuels

Fuel	CO ₂	CO	NO _x	HC	PM	Fuel Use
SwD	205.6	0.4	1.9	0.2	0.047	98.81
SwD+OXC	211.1	0.4	1.9	0.2	0.033	101.97
SwDhol	200.0	0.5	2.0	0.2	0.030	99.72
SwDhol+OXC	200.0	0.4	2.0	0.2	0.017	98.39
EDsl	205.6	0.4	1.9	0.2	0.061	97.42
EDhol	205.6	0.5	2.0	0.2	0.039	100.11

OXC = Oxidation catalyst

¹ Westerholm, R., Christensen, A., Tornqvist, M., Ehrenberg, L. & Haupt, D. (1997) Chemical and biological characterisation of exhaust emissions from ethanol and ethanol blended diesel fuels in comparison with neat diesel fuels, KFB Report 1997:17, Kommunikations Forsknings Beredningen (Swedish Transport and Communications Research Board) Stockholm.

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The ACTION bus fleet in Canberra trialed three new buses running on diesohol (Scott et al., 1995; Joseph, 1996). Sydney buses also used such buses, until 1998, from their Burwood depot (Figure 7.1) and the results of emission testing of these buses is given in APACE Research Ltd (1999).

The tests on diesohol that were conducted by the NSW EPA (Scott et al., 1995) compared the performance of three ACTION ethanol-fuelled buses with three buses fuelled by diesel. The results are given in g/kWh. They have been converted to g/MJ and to g/km on the basis of the observed fuel consumption, which ranged from 217 to 341 g/kWh, and on the fuel economy, which ranged from 36.79 L/100 km to 46.96 L/100 km. The density for all fuels was assumed to be 840 g/L. The results are summarised in Table 7.4, Table 7.5 and Table 7.6. We have analysed the results presented on both the Canberra and Sydney buses

Table 7.4
Results of testing of Canberra buses (Scott et al., 1995; Joseph, 1996)

Fuel	CO₂	CO	NO_x	HC	Fuel Use
Diesohol (g/MJ)	296	0.47	4.25	0.25	101
Diesel (g/MJ)	296	0.39	4.81	0.25	95
Diesohol (g/km)	981	1.57	14.09	0.83	
Diesel (g/km)	963	1.27	15.66	0.81	

Table 7.5
Results of testing of Sydney buses (APACE Research Pty Ltd, 1999)

Fuel	CO₂	CO	NO_x	HC	PM	Fuel Use
Diesel (g/MJ)	212	0.22	1.98	0.14	0.05	60.8
E15 (g/MJ)	212	0.25	1.88	0.15	0.04	65.6
E17 (g/MJ)	210	0.22	1.97	0.14	0.04	65.0
E20 (g/MJ)	213	0.25	1.87	0.15	0.03	66.4
LSD (g/MJ)	207	0.22	2.08	0.17	0.04	60.3
LSDiesohol(E15) (g/MJ)	206	0.26	1.97	0.16	0.03	65.6
Diesel (g/km)	1310	1.37	12.20	0.89	0.28	
E15 (g/km)	1274	1.49	11.33	0.89	0.24	
E17 (g/km)	1274	1.31	11.95	0.84	0.21	
E20 (g/km)	1263	1.49	11.09	0.91	0.20	
LSD (g/km)	1291	1.39	12.97	1.04	0.25	
LSDiesohol(E15) (g/km)	1242	1.57	11.85	0.99	0.19	

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Table 7.6
Results of testing of Sydney buses for air toxics (APACE Research Pty Ltd.)

Fuel	Formaldehyde	Acetaldehyde.
Diesel (g/MJ)	0.0014	0.0033
E15 (g/MJ)	0.0011	0.0061
E17 (g/MJ)	0.0017	0.0061
E20 (g/MJ)	0.0014	0.0067
LSD (g/MJ)	0.0022	0.0061
LSDiesohol(E15) (g/MJ)	0.0019	0.0058
Diesel (g/km)	0.0086	0.0206
E15 (g/km)	0.0064	0.0350
E17 (g/km)	0.0096	0.0353
E20 (g/km)	0.0079	0.0377
LSD (g/km)	0.0139	0.0381
LSDiesohol(E15) (g/km)	0.0111	0.0334

In addition, Scott et al. (1995: Table 25) present a summary of the aldehyde emissions from Canberra buses using diesohol, in concentration units. At a speed of 50 km/h under 25% load, the formaldehyde emissions are as given in Table 7.7.

Table 7.7
Concentrations of aldehydes emitted from Canberra buses at 50 km/hr under 25% load.

Fuel	Formaldehyde	Acetaldehyde	Acrolein	Total Aldehydes
Diesohol (ppmv)	0.658	1.667	0.483	2.792
Diesel (ppmv)	0.783	1.342	0.85	2.958

7.5 Full Fuel-Cycle Analysis of Emissions

APACE Research (R. Reeves, personal communication) provided estimates of the life-cycle carbon dioxide emissions of diesohol using the energy balance method of Lynd (1996). These calculations are reproduced in Appendix 6. They claim the following emissions:

- 80 gCO₂/MJ for diesel fuel
- 28 gCO₂/MJ for Manildra azeotropic ethanol
- 31 gCO₂/MJ for Manildra anhydrous ethanol
- 4 gCO₂/MJ for CSR azeotropic ethanol from molasses
- 16 gCO₂/MJ for ethanol from dedicated lignocellulosic crops
- 6 gCO₂/MJ for ethanol from lignocellulosic residue material.

These values may be compared with those calculated by Beer et al. (2000) who estimated life-cycle CO₂ emissions to be 80 gCO₂/MJ for diesel fuel and 36 gCO₂/MJ for ethanol from lignocellulose. We believe that discrepancy between this latter value, obtained using a bottom-up approach and the 16gCO₂/MJ estimated by APACE, using a top-down approach are indicative of the range of uncertainty associated with estimates of full fuel cycle greenhouse gas emissions.

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Despite the energy savings associated with lignocellulosic ethanol, there is no commercial production of such ethanol in Australia. Even though the buses that were tested in the diesohol tests used diesohol with the ethanol made from wheat starch waste, our calculations are based on an expected supply of ethanol from molasses from Sarina.

7.5.1 Emissions on a mass per unit energy basis

The results obtained by using the SimaPro life-cycle model along with the upstream and tailpipe emissions data specified in the previous chapters of this report are given in Table 7.8 for the full life cycle for greenhouse gases and criteria pollutants. The upstream emissions and the tailpipe emissions that comprise these totals are given in Table 7.9 and Table 7.10 respectively. The greenhouse gas emissions are graphed in Figure 7.3.

Table 7.8
Urban and total life-cycle emissions (per MJ) calculated for diesel and diesohol

Full Lifecycle	Units	LS Diesel	Diesohol
Greenhouse	kg CO ₂	0.0858	0.0800
HC total	g HC	0.140	0.133
HC urban	g HC	0.111	0.106
NOx total	g NOx	1.044	0.966
NOx urban	g NOx	0.987	0.912
CO total	g CO	0.253	0.335
CO urban	g CO	0.242	0.325
PM10 total	mg PM10	40.7	31.8
PM10 urban	mg PM10	39.3	30.5
Energy Embodied	MJ LHV	1.18	1.11

The results separate urban and total emissions. Emissions were assumed to occur in urban areas unless they were produced by a known rural or maritime activity.

The apparent discrepancies in certain values, when compared with tabulations earlier in this report, arise because many of the values that are reported in the main text are in terms of g/MJ measured as usable energy from the engine driveshaft (normally represented as g/kWh), whereas the life-cycle calculations are consistent in setting all the calculations in terms of g/MJ based on the inherent chemical energy of the fuel. On average, this reduces quoted engine dynamometer values by a factor of 3.

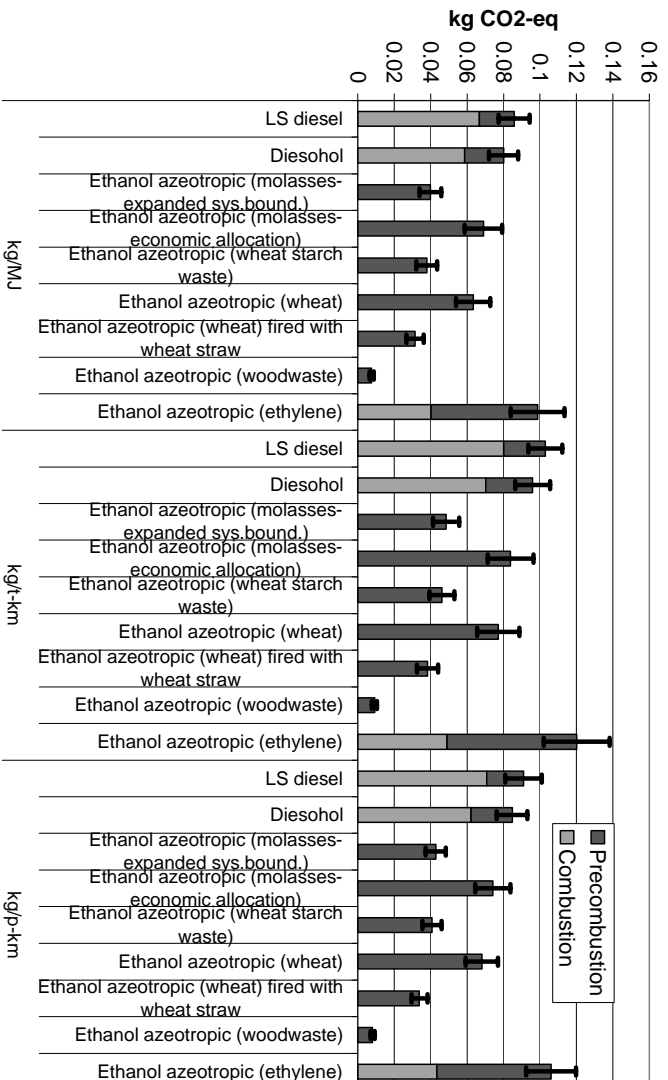


Figure 7.3 Life-cycle emissions of greenhouse gas emissions for low sulfur diesel, diesohol and ethanol.

Table 7.9 Urban and total upstream emissions (per MJ) for diesel and diesohol

Precombustion	Units	LS Diesel (Aus)	Diesohol
Greenhouse	kg CO ₂	0.0191	0.0214
HC total	g HC	0.0565	0.0532
HC urban	g HC	0.027	0.026
NOx total	g NOx	0.100	0.103
NOx urban	g NOx	0.043	0.049
CO total	g CO	0.023	0.075
CO urban	g CO	0.012	0.065
PM10 total	mg PM10	5.42	4.97
PM10 urban	mg PM10	4	3.63
Energy Embodied	MJ LHV	1.18	1.11

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Table 7.10
Urban and total tailpipe emissions (per MJ) from diesel and diesohol

Combustion	Units	LS Diesel	
		(Aus)	Diesohol
Greenhouse	kg CO ₂	0.0667	0.059
HC total	g HC	0.0835	0.080
HC urban	g HC	0.0835	0.080
NOx total	g NOx	0.944	0.863
NOx urban	g NOx	0.944	0.863
CO total	g CO	0.230	0.260
CO urban	g CO	0.230	0.260
PM10 total	mg PM10	35.3	26.82
PM10 urban	mg PM10	35.3	26.82
Energy Embodied	MJ LHV	0	0

7.5.2 Vehicle emissions - trucks (g/km)

This section gives the calculated values for the emissions from trucks, on a per-kilometre basis.

Table 7.11
Urban and total life cycle emissions (per km) for trucks calculated for diesel and diesohol

Full LC	Units	LS Diesel	
		engine	Diesohol engine
Greenhouse	kg CO ₂	0.9250	0.8619
HC total	g HC	1.509	1.430
HC urban	g HC	1.192	1.141
NOx total	g NOx	11.250	10.402
NOx urban	g NOx	10.638	9.823
CO total	g CO	2.723	3.606
CO urban	g CO	2.612	3.501
PM10 total	mg PM10	438.4	342.3
PM10 urban	mg PM10	423.1	327.9
Energy Embodied	MJ LHV	12.7	11.90

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Table 7.12
Urban and total precombustion emissions (per km) for trucks calculated for diesel and diesohol

Precombustion		LS Diesel (Aus)	Diesohol
Greenhouse	kg CO ₂	0.2060	0.2310
HC total	g HC	0.609	0.573
HC urban	g HC	0.292	0.284
NOx total	g NOx	1.080	1.110
NOx urban	g NOx	0.468	0.531
CO total	g CO	0.243	0.805
CO urban	g CO	0.132	0.700
PM10 total	mg PM10	58.4	53.5
PM10 urban	mg PM10	43.1	39.1
Energy Embodied	MJ LHV	12.7	11.9

Table 7.13
Urban and total tailpipe emissions (per km) for trucks calculated for diesel and diesohol

Combustion		LS Diesel (Aus)	Diesohol
Greenhouse	kg CO ₂	0.719	0.631
HC total	g HC	0.900	0.857
HC urban	g HC	0.900	0.857
NOx total	g NOx	10.17	9.292
NOx urban	g NOx	10.17	9.292
CO total	g CO	2.48	2.801
CO urban	g CO	2.48	2.801
PM10 total	mg PM10	380	288.80
PM10 urban	mg PM10	380	288.80
Energy Embodied	MJ LHV	0	0

7.5.3 Vehicle emissions - buses (g/km)

This section gives the calculated values for the emissions from buses, on a per-kilometre basis. The greenhouse gas emissions and the particulate matter emissions are graphed in Figure 7.3.

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Table 7.14
Urban and total life-cycle emissions for buses (per km) calculated for diesel and diesohol

Full LC		LS Diesel	Diesohol
Greenhouse	kg CO ₂	1.66	1.55
HC total	g HC	2.71	2.57
HC urban	g HC	2.14	2.05
NOx total	g NOx	20.20	18.68
NOx urban	g NOx	19.10	17.64
CO total	g CO	4.89	6.48
CO urban	g CO	4.69	6.29
PM10 total	mg PM10	787	614.62
PM10 urban	mg PM10	760	588.77
Energy Embodied	MJ LHV	22.8	21.37

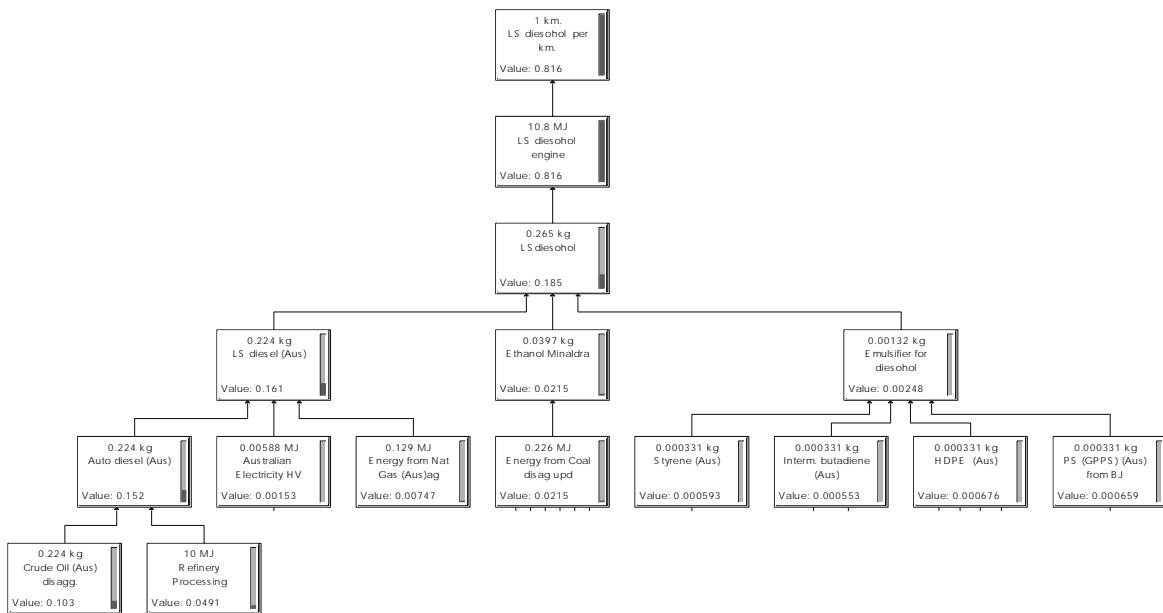


Figure 7.4
Embodied greenhouse gases emissions (kg CO₂-eq) from diesohol production, processing and use in vehicle

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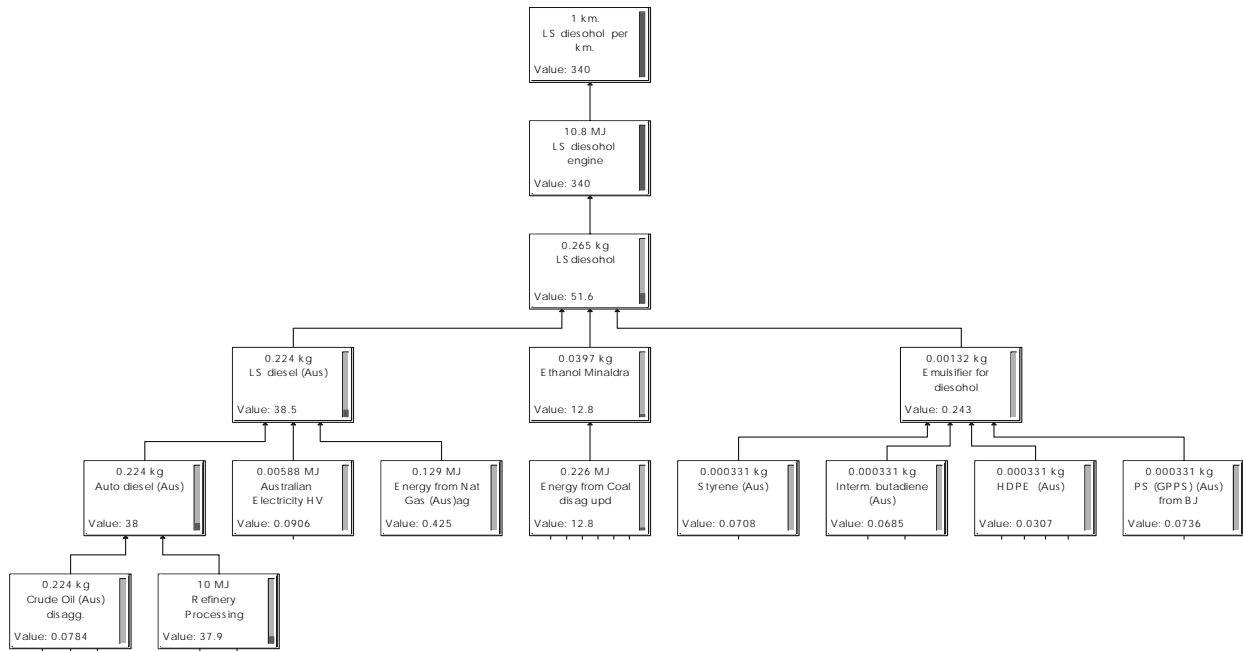


Figure 7.5
Embodied particulate matter (mg - urban) from diesohol production, processing and use in vehicle

Table 7.15
Urban and total precombustion emissions for buses (per km) calculated for diesel and diesohol

Precombustion		LS Diesel (Aus)	Diesohol
Greenhouse	kg CO ₂	0.37	0.41
HC total	g HC	1.09	1.03
HC urban	g HC	0.52	0.51
NOx total	g NOx	1.94	1.99
NOx urban	g NOx	0.84	0.95
CO total	g CO	0.44	1.45
CO urban	g CO	0.24	1.26
PM10 total	mg PM10	104.9	96.06
PM10 urban	mg PM10	77.4	70.21
Energy Embodied	MJ LHV	22.80	21.37

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Table 7.16
Urban and total tailpipe emissions for buses (per km) calculated for diesel and diesohol

Combustion		LS Diesel (Aus)	Diesohol
Greenhouse	kg CO ₂	1.29	1.133
HC total	g HC	1.62	1.538
HC urban	g HC	1.62	1.538
NOx total	g NOx	18.26	16.684
NOx urban	g NOx	18.26	16.684
CO total	g CO	4.45	5.030
CO urban	g CO	4.45	5.030
PM10 total	mg PM10	682.31	518.56
PM10 urban	mg PM10	682.31	518.56
Energy Embodied	MJ LHV	0.00	0

7.5.4 Uncertainties

We use the uncertainty estimates given by Beer et al. (2000) on the basis of the tailpipe emissions to estimate the uncertainties associated with the above results to be as given in Table 7.17.

Table 7.17
Estimated one standard deviation uncertainties (in percent) for diesohol emissions

	g/MJ	g/t-km	g/p-km
CO ₂	10	10	10
HC	45	17	73
NOx	17	26	8
CO	51	36	66
PM10	45	45	45

7.6 Viability and Functionality

The flash point of the emulsion becomes that of alcohol when the alcohol content exceeds 5% of the volume. Above a 15% ethanol blend an ignition improver is needed, whereas above 25% ethanol engine modifications are required.

Two problems have been found to date with the use of diesohol according to discussions with Mr Ernie Lom and Dr Russell Reeves of APACE Research Ltd. The first of these is comparable to those with the use of low sulfur diesel, and relate to fuel injection equipment components. The components are: i) some T valves fitted to Bosch type feed pumps swell excessively and result in the valve stem becoming jammed; ii) the drive shaft seal fitted to Nipon Denso rotary pumps can swell and soften resulting in fuel leakage; iii) some filter glues, impregnation resins and epoxy resins (such as in DPA pump and RBA transfer pump blades) are susceptible and need to be identified in service.

The second problem, which has been fixed with the installation of booster pumps, concerns the need to ensure that vapour locks do not occur. Adding ethanol changes the vaporization potential of diesel. Evaporative emissions of VOC from vehicles increase when vapour pressure of the fuel is increased or the ambient temp rises (Carnovale et al., 1991). Diesel fuel has a very low vapour pressure but the addition of alcohol to diesel in diesohol creates a fuel with a similar vapour pressure to ethanol. While modern gasoline vehicles have evaporative

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emissions control measures, diesel vehicles do not. Evaporative emissions may be a significant problem from unmodified vehicles using diesohol, but this needs to be tested. To control evaporative emissions from vehicles using alcohol fuels, measures may need to be implemented to control fuel vapour pressure, and control evaporative emissions from diesel fuel vehicles. APACE Research Ltd ensures that there are no vapour locks by installing a booster pump (E. Lom, pers. comm.).

They also point out that diesohol was the only emulsified fuel to pass stability test conducted by Shell. To date diesohol has been a niche fuel and thus the situation with respect to availability and warranty has not been clarified. During testing of buses using diesohol, the fuel was blended by delivering diesel to Manildra, near Nowra, and blending the diesel with ethanol and emulsifier.

7.7 *Health and OHS*

7.7.1 *Production and transport*

The ethanol used in Australia is manufactured from biomass from the fermentation of sugar derived from grain or sugar crops. Production of these feedstock crops results in a range of particles and air toxic emissions.

Feedstock transport to the ethanol production facility results in a range of particles and air toxic emissions. These will be detailed in subsequent work that deals solely with ethanol. In this review of diesohol, these contributions are noted by the difference in value between the last two columns of Table 7.9. This approach is taken because we were specifically asked to compare each fuel (diesohol in this case) against LSD as the reference fuel. Similarly, emissions of particulate matter and air toxics could be expected from the ethanol production process. The process includes high temperature cooking and fermentation, which emits acetaldehyde.

As the composition of diesohol is 85% diesel the production and transport emissions associated with diesohol production are assumed to be similar to LSD, except for the ethanol and emulsifier component. The emulsifier consists of a styrene-butadiene copolymer dissolved in the diesel fuel that, by steric stabilisation, couples with a polyethyleneoxide-polystyrene (PEOPS) copolymer dissolved in the hydrated alcohol. Manufacture of the emulsifier involves butadiene, which is an air toxic. However, the quantities of emulsifier are small (0.5% v/v) compared to the quantities of diesel and ethanol. Consequently the amount of butadiene is very low.

Particulate matter

The urban precombustion (truck) PM10 estimate for LSD is 43 mg/km compared to 39 mg/km for diesohol (Table 7.12).

Air toxics

The urban precombustion (truck) HC estimate for LSD is 0.292 g/km compared to 0.284 g/km for diesohol (Table 7.12). The public health effects of air toxics will be mainly associated with combustion emissions in the large urban centres.

An accompanying disk to this report from provides details of air toxics emissions from upstream activities.

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7.7.2 Use

APACE Research results, as summarised in Table 7.5, indicate that compared to LSD emissions, diesohol (E15) emissions have marginally higher CO emissions, but marginally lower NO_x and HC emissions.

Particulate matter

The APACE Research results (Table 7.5) indicate that, compared to LSD emissions, diesohol (E15) emissions have lower PM emissions. The values are 0.04 g/MJ (0.25 g/km) for LSD and 0.03 g/MJ (0.19g/km) for diesohol made from low sulfur diesel. The combustion (truck) PM₁₀ estimate from the LCA for LSD is 380 mg/km compared to 289 mg/km for diesohol.

Air toxics

The APACE Research results (Table 7.6) also indicate that compared to LSD emissions, diesohol (E15) emissions have marginally lower acetaldehyde emissions – 0.038 g/km for LSD compared to 0.033 g/km for LSDiesohol (i.e. diesohol made with low sulfur diesel). However, the Swedish Euro2 bus study found emissions of 0.02 g/km acetaldehyde (Ahlvik & Brandberg, 2000) using low sulfur diesel. This provides a measure of the variability in the data and hence the uncertainty in the results.

There are lower formaldehyde emissions using diesohol. Low sulfur diesel emits from 0.014 g/km, whereas LSDiesohol emits 0.011 g/km. Table 7.7 also indicates that acrolein emissions will be lower with diesohol than with diesel fuels.

Information for diesohol was not available for the other air toxics. However the diesohol HC emissions were marginally lower compared to LSD for the APACE Research results. The combustion (truck) HC (assumed to be equivalent to NMVOC) estimate for LSD is 0.900 g/km compared to 0.857 g/km for diesohol.

7.7.3 Diesohol emissions summary

As the composition of diesohol is 85% diesel the production and transport emissions associated with diesohol production are assumed to be similar to LSD. The LCA indicates that urban precombustion PM₁₀ emissions of diesohol (39 mg/km or 3.63 mg/MJ) are marginally lower than LSD (43 mg/km or 4.0 mg/MJ), though the urban precombustion HC emissions are similar at 0.29 g/km or 0.026 g/MJ.

The LCA indicates that combustion PM emissions from diesohol (289 mg/km or 26.8 mg/MJ) are lower than LSD (380 mg/km or 35.3 mg/MJ).

There is limited information available on air toxic emissions for diesohol. The high proportion of diesel in diesohol suggests that the air toxic emissions are unlikely to be substantially different to LSD. The LCA indicates that HC combustion emissions of diesohol are similar to LSD

7.7.4 OHS Issues

The flash point and flammability characteristics of diesohol are those of alcohol. This requires that diesohol be considered and handled as gasoline (petrol) rather than as diesel fuel, even though the flash point of petrol is considerably lower than that of ethanol (13°C). In practical terms, APACE Research handles the fuel as it would ethanol to ensure safety. Ethanol in solution is hazardous according to Worksafe Australia, with high flammability, moderate toxicity, and a moderate irritant.

Occupation exposure of drivers to diesohol vapours during HDV refuelling was assessed by Workcover in 1992 (NSW Workcover Authority, 1999). Normally refuelling is conducted by

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keeping the fuel dispensing nozzle in the automatic mode with only the last 10-12 litres added manually. The drivers are normally only exposed to diesohol vapours during manual refuelling. The results indicate that levels of diesohol vapours are low and do not represent a significant health hazard to drivers.

7.8 *Environmental Issues*

The present use of ethanol, as in diesohol, is that of a niche fuel. As such, there are no issues related to sustainability. However, if ethanol were to become a dominant fuel then it would have to be based on ligno-cellulose. Foran and Mardon (1999) contains details of ethanol and methanol production technology and supply constraints, and of the environmental consequences of both crop and fuel production processes. They claim that if ligno-cellulosic ethanol production is used then it would be possible to establish biomass plantations over the next 50 years that meet 90% of Australia's oil requirements, and specifically to supply all transportation fuels. To do this using ethanol requires biomass production to cover up to 19 million hectares of Australia's croplands and high rainfall pasture zones. Their modelling approach envisages substantial environmental benefit. In addition to the reduction in greenhouse gas emissions (up to 300 million tonnes by the year 2050), the large-scale planting of tree and shrub crops as ethanol feedstock would help to control dryland salinity and associated problems.

The environmental impact from the production of diesohol are the same as those from the production of the diesohol feedstocks; namely diesel as ethanol, and will be dealt with in the relevant chapters.

In particular, we draw attention to the fact that appropriate disposal of the refinery waste-products is crucial to environmental impacts or benefits. Dunder application is often criticised as being the cause of poor waste quality in Queensland, though there is little evidence of this (www.sunfish.org.au/fishkills/fishkills.htm). Conversely, appropriate and careful disposal of dunder means that many farmers in the district near Sarina now use it as a fertiliser and soil condition - even though it was once considered a poison.

We are not aware of any issues related to groundwater contamination.

7.9 *Expected Future Emissions*

Arcoumanis (2000) developed a model that examines a given alternative fuel relative to the reference diesel engine (Euro2) in terms of a specific regulated pollutant. A value of 1 implies identical performance to the low sulfur diesel/Euro2 combination. A value greater than 1 implies inferior performance, whereas a value less than 1 indicates superior performance.

Table 7.18 lists the estimated emissions factors for diesohol. The columns in bold represent the standards relative to the Euro2 standard. The adjacent column gives the expected performance of diesohol. The estimates of Arcoumanis (2000) indicate that diesohol can be expected to meet all future Australian Design Rules for all pollutants except total hydrocarbon which may be slightly above Euro3 and Euro4 standards.

Table 7.18
Estimated relative emission factors for diesohol under future technologies.
Euro2 diesel (shown in bold) are taken as 1.0

Technology	CO	CO	THC	THC	NOx	NOx	PM	PM	CO ₂	LCA CO ₂
Euro2	1.0	1.1	1.0	1.1	1.0	0.8	1.0	0.6	1.0	0.9
Euro3	0.53	0.5	0.6	0.7	0.71	0.6	0.67	0.4	1.0	0.9
Euro4	0.38	0.4	0.42	0.5	0.5	0.4	0.2	0.1	1.0	0.9

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APACE Research advises that vapour lock problems had led to higher THC and CO emissions as reflected in Arcoumanis (2000). APACE has indicated that the addition of a booster pump now overcomes vapour lock problems and the resulting THC and CO problems. This means that LSdiesohol should be able to meet future ADRs.

7.10 Summary

7.10.1 Advantages

- As a partly renewable fuel it produces less fossil CO₂ than conventional fuels.
- Particulate emissions are lowered.
- 1,3 butadiene and benzene levels decrease as the ethanol concentration increases.
- Lower sulfur content than conventional diesel.

7.10.2 Disadvantages

- Overseas, the chemical emulsifiers used to blend ethanol and diesel contain harmful chemicals. According to APACE the chemical emulsifier that they use is composed only of hydrocarbons and oxygen and is thus no more harmful than diesel fuel.

7.11 Appendix to Diesohol Fuel Chapter

This appendix (Appendix 6) comprises a separate file of scanned material provided by APACE.

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