

13. Anhydrous Ethanol

13.1 Background

Development and use of alcohol fuels in transport have for the most part been driven by the desire in many countries to find renewable substitutes for imported petroleum-based fuels. Alcohol fuels have also been used as additives to conventional fuels to improve fuel characteristics. For petrol blends, ethanol is a known octane enhancer (a component added to petrol to increase octane rating and reduce engine knock) and oxygenate (a fuel or fuel additive containing hydrogen, carbon and oxygen in its molecular structure). Ethanol will easily blend with gasoline but blending with diesel requires an emulsifier or additive to form a stable fuel. Alcohols can be used in diesel engines by either modifying the fuel or by extensive engine adaptations.

More recently alcohol fuels have been the focus of attention as a possible means of reducing greenhouse gas emissions, and noxious urban emissions from transport. Results from several studies that have been conducted throughout the world on exhaust emissions from ethanol blended fuels are often contradictory, making it difficult to generalise on emission outcomes and performance of ethanol blends. Furthermore, the tailpipe emissions from ethanol blended fuels varies markedly between different ethanol blends and different vehicle technologies.

Ethanol can be produced in two forms – hydrated and anhydrous. Hydrated ethanol has a purity of 95% suitable for blending with an ignition improver, or as a 15% emulsion in diesel that is known as diesohol. A second stage refining process is required to produce anhydrous ethanol (100% purity) for use in ethanol blends in petrol. Most industrial ethanol is denatured (to prevent oral consumption) by the addition of small amounts of an unpleasant or poisonous substance.

Anhydrous ethanol can be used as an additive in petrol, or as a fuel in its own right. Despite this, as an automotive fuel it is usually composed of 85% ethanol with 15% petrol (E85P) and this is the fuel that will be examined in this chapter. The reason for this is that the addition of 15% petrol improves the ignitability of alcohol, especially at low temperature. Other additives have also been trialled as ignition improvers. Ethanol is probably the most widely used alternative automotive fuel in the world, mainly due to Brazil's decision to produce fuel alcohol from sugar cane. Previous chapters have discussed diesohol, petrohol, and hydrated ethanol (for heavy vehicles). Because the only differences between hydrated and anhydrous ethanol are (i) the extra energy required for distillation, and (ii) the absence of an emulsifier when the anhydrous ethanol is blended with petrol, this chapter will deal with the use of anhydrous ethanol as a fuel for cars.

13.2 Full Fuel-Cycle Emissions

The upstream emissions associated with anhydrous ethanol are essentially the same as those associated with hydrated ethanol, with a requirement for extra energy input arising from the extra process step to transform the hydrated ethanol to anhydrous ethanol. According to Table 10 of the chapter on hydrated ethanol, 30% more energy is needed to convert hydrated ethanol to anhydrous ethanol. Our calculations also include the emissions associated with the production of the 15% of petrol added to the anhydrous ethanol.

13.2.1 Tailpipe emissions

Table 13.1 gives the tailpipe emissions (in kg) over the life of a typical vehicle using petrol and using oxygenated petrol (Maclean, 1998; 2000)

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Table 13.1
Lifetime exhaust emissions (kg) of air pollutants and carbon dioxide from petrol and oxygenated petrol

	NMHC	CO	NO _x	PM	THC	CO ₂
Petrol	36	494	58	12	60	53,676
E85P	35±35	536±484	38±38		66±66	48,564*

*Renewable carbon, 85% of which is not considered to be a greenhouse gas.

These results agree with those of Arcoumanis (2000) who examined ethanol fuel for passenger cars and noted that tailpipe emissions of CO and hydrocarbons were 10% above Euro2 standards, NO_x was 20% below Euro2, CO₂ emissions were comparable, but particulate matter emissions were about half those of petrol vehicles.

13.3 Results

Wang et al. (1999) conducted a detailed study of the use of corn ethanol in the United States in terms of full fuel cycle energy and greenhouse gas emissions. Representative values for the results for the life cycle emissions associated with the use of anhydrous ethanol may be found in the chapter on hydrated ethanol. These may be taken as representative values when considered on a g/MJ, or g/km basis. When anhydrous ethanol is used in automobiles, the results will differ when expressed on a g/t-km basis. The variability and uncertainties associated with both forms of ethanol are expected to be the same.

13.3.1 Emissions on a mass per unit energy basis

Table 13.2
Embodied emissions per MJ for premium unleaded petrol (PULP) and ethanol (mixed with 15% PULP)

Full Lifecycle	Units	PULP	Ethanol azeotropic (molasses-expanded sys.bound.)	Ethanol azeotropic (molasses-economic allocation)	Ethanol azeotropic (wheat starch waste)	Ethanol azeotropic (wheat)	Ethanol azeotropic (wheat) fired with wheat straw	Ethanol azeotropic (woodwaste)	Ethanol azeotropic (ethylene)
Greenhouse	kg								
	CO ₂	0.0888	0.0440	0.0679	0.0401	0.0651	0.0364	0.0173	0.1464
HC total	g HC	0.170	0.136	0.134	0.128	0.180	0.903	0.556	0.572
HC urban	g HC	0.141	0.126	0.126	0.120	0.126	0.849	0.548	0.507
NO _x total	g								
	NO _x	0.185	0.186	0.185	0.162	0.325	0.276	0.128	0.343
NO _x urban	g								
	NO _x	0.129	0.148	0.168	0.147	0.182	0.133	0.113	0.297
CO total	g CO	0.930	1.438	1.562	1.000	1.606	3.916	2.476	1.044
CO urban	g CO	0.920	1.431	1.558	0.997	1.002	3.306	2.476	1.028
PM10 total	mg								
	PM10	38.2	35.0	34.5	51.2	53.5	72.9	55.0	38.3
PM10 urban	mg								
	PM10	36.9	34.2	34.1	50.8	51.0	70.3	54.6	37.5
Energy embodied	MJ								
	LHV	1.14	0.61	0.66	0.62	0.85	0.94	2.40	3.00

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Table 13.3
Precombustion emissions per MJ for premium unleaded petrol (PULP) and ethanol (mixed with 15% PULP)

Precombustion Units	PULP	Ethanol azeotropic (molasses-expanded sys.bound.)	Ethanol azeotropic (molasses-economic allocation)	Ethanol azeotropic (wheat starch waste)	Ethanol azeotropic (wheat)	Ethanol azeotropic (wheat) fired with wheat straw	Ethanol azeotropic (woodwaste)	Ethanol azeotropic (ethylene)	
Greenhouse	kg CO ₂	0.0177	0.0377	0.0616	0.0338	0.0588	0.0301	0.0110	0.0821
HC total	g HC	0.0543	0.0231	0.0219	0.0158	0.0673	0.791	0.444	0.46
HC urban	g HC	0.026	0.013	0.014	0.008	0.014	0.737	0.436	0.395
NOx total	g NOx	0.094	0.126	0.125	0.102	0.265	0.216	0.068	0.283
NOx urban	g NOx	0.038	0.088	0.108	0.087	0.122	0.073	0.053	0.237
CO total	g CO	0.021	0.452	0.576	0.014	0.620	2.930	1.490	0.058
CO urban	g CO	0.011	0.445	0.572	0.011	0.015	2.320	1.490	0.041
PM10 total	mg PM10	5.19	1.96	1.48	18.1	20.4	39.8	21.9	5.25
PM10 urban	mg PM10	3.8	1.16	1.06	17.7	17.9	37.2	21.5	4.48
Energy embodied	MJ LHV	1.14	0.61	0.66	0.62	0.85	0.94	2.40	3.00

Table 13.4
Combustion emissions per MJ for premium unleaded petrol (PULP) and ethanol (mixed with 15% PULP)

Combustion	Units	PULP	Anhydrous Ethanol with 15% PULP
Greenhouse	kg CO ₂	0.071	0.006
HC total	g HC	0.116	0.112
HC urban	g HC	0.116	0.112
NOx total	g NOx	0.091	0.060
NOx urban	g NOx	0.091	0.060
CO total	g CO	0.909	0.986
CO urban	g CO	0.909	0.986
PM10 total	mg PM10	33.06	33.06
PM10 urban	mg PM10	33.06	33.06
Energy embodied	MJ LHV	0	0

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13.3.2 Vehicle emissions - cars (g/km)

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

Table 13.5
Exbodied emissions per km for premium unleaded petrol (PULP) and ethanol (mixed with 15% PULP)

Full Lifecycle	Units	PULP	Ethanol azeotropic (molasses-expanded sys.bound.)	Ethanol azeotropic (molasses-economic allocation)	Ethanol azeotropic (wheat starch waste)	Ethanol azeotropic (wheat)	Ethanol azeotropic (wheat) fired with wheat straw	Ethanol azeotropic (woodwaste)	Ethanol azeotropic (ethylene)
Greenhouse	kg								
	CO ₂	0.2148	0.1062	0.1641	0.0969	0.1571	0.0879	0.0417	0.3546
HC total	g HC	0.412	0.328	0.325	0.311	0.435	2.182	1.352	1.382
HC urban	g HC	0.342	0.304	0.306	0.291	0.306	2.052	1.332	1.227
NOx total	g								
	NOx	0.447	0.448	0.446	0.392	0.785	0.668	0.309	0.830
NOx urban	g								
	NOx	0.313	0.358	0.405	0.355	0.439	0.321	0.273	0.718
CO total	g CO	2.251	3.477	3.777	2.421	3.887	9.477	5.997	2.526
CO urban	g CO	2.227	3.467	3.767	2.414	2.424	8.007	5.987	2.487
PM10 total	mg								
	PM10	92.5	84.8	83.6	123.7	129.4	176.2	132.9	92.7
PM10 urban	mg								
	PM10	89.2	82.8	82.6	122.8	123.3	170.1	132.0	90.8
Energy embodied	MJ LHV	2.75	1.48	1.59	1.50	2.05	2.27	5.80	7.26

Table 13.6
Precombustion emissions per km for premium unleaded petrol (PULP) and ethanol (mixed with 15% PULP)

Precombustion Units	PULP	Ethanol azeotropic (molasses-expanded sys.bound.)	Ethanol azeotropic (molasses-economic allocation)	Ethanol azeotropic (wheat starch waste)	Ethanol azeotropic (wheat)	Ethanol azeotropic (wheat) fired with wheat straw	Ethanol azeotropic (woodwaste)	Ethanol azeotropic (ethylene)
Greenhouse	kg							
	CO ₂	0.0428	0.0911	0.1490	0.0818	0.1420	0.0728	0.1990
HC total	g HC	0.132	0.0559	0.053	0.0383	0.163	1.91	1.11
HC urban	g HC	0.062	0.032	0.033	0.019	0.033	1.780	0.955
NOx total	g							
	NOx	0.227	0.304	0.302	0.248	0.641	0.524	0.686
NOx urban	g							
	NOx	0.093	0.214	0.261	0.211	0.295	0.177	0.574
CO total	g CO	0.051	1.090	1.390	0.034	1.500	7.090	0.139
CO urban	g CO	0.027	1.080	1.380	0.027	0.037	5.620	0.100
PM10 total	mg							
	PM10	12.5	4.75	3.58	43.7	49.4	96.2	52.9
PM10 urban	mg							
	PM10	9.19	2.81	2.58	42.8	43.3	90.1	52
Energy embodied	MJ LHV	2.75	1.48	1.59	1.5	2.05	2.27	5.8

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Table 13.7
Tailpipe emissions per km for premium unleaded petrol (PULP) and ethanol (mixed with 15% PULP)

Combustion	Units	PULP	Ethanol
Greenhouse	kg CO ₂	0.172	0.015
HC total	g HC	0.280	0.272
HC urban	g HC	0.280	0.272
NOx total	g NOx	0.220	0.144
NOx urban	g NOx	0.220	0.144
CO total	g CO	2.200	2.387
CO urban	g CO	2.200	2.387
PM10 total	mg PM10	80.00	80.00
PM10 urban	mg PM10	80.00	80.00
Energy embodied	MJ LHV	0	0

13.3.3 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 6.19.

Table 13.8
Estimated one standard deviation uncertainties (in percent) for hydrated ethanol emissions

	g/MJ	g/t-km	g/p-km
CO ₂	15	15	13
HC	45	17	73
NOx	21	8	35
CO	40	36	46
PM10	46	45	46

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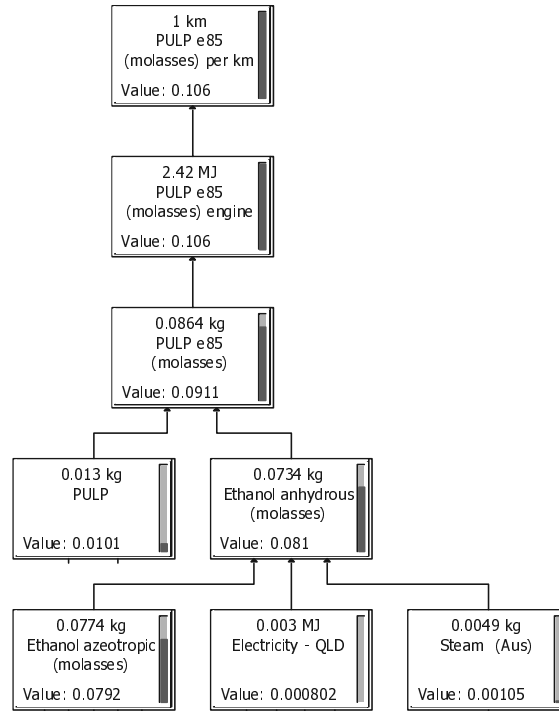


Figure 13.1

Embodied greenhouse gases emissions (kg CO₂eq) from E85 in PULP production and processing and use in vehicle (Ethanol component is from molasses based on Sarina plant and using expanded system boundary allocation)

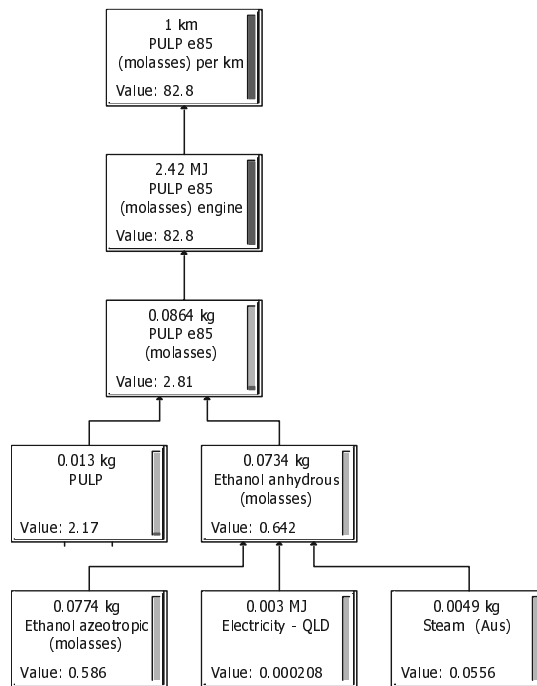


Figure 13.2

Embodied particulate matter (mg - urban) from E85 in PULP production and processing and use in vehicle (Ethanol component is from molasses based on Sarina plant and using expanded system boundary allocation)

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13.4 Viability and Functionality

There is considerable international experience on the use of ethanol in Brazil where sugar-derived ethanol is used as an automotive fuel. The ethanol used in Brazil is called Alcool and consists of 93% ethanol by volume. IEA Alternative Fuels Information Service (1996) note that “the techniques for the production and use of methanol and ethanol as a vehicle fuel are known. Obstacles that hinder the use of alcohols as a vehicular fuel are the relatively high costs of alcohol and the investments necessary to introduce an extra fuel.”

The viability and functionality issues related to ethanol and its use in heavy vehicles (as diesohol) or in light vehicles (as petrohohol) have been examined in previous chapters, and the same considerations will apply.

13.5 Health and OHS

Table 13.9 gives the exhaust emissions of air toxics given by MacLean (1988) that may also be found in the supporting documentation of MacLean and Lave (2000). The air toxic emissions are given in terms of mass emitted per vehicle lifetime, but are also given in terms of weighted emissions in terms of sulfuric acid equivalents. In both cases, ethanol produces a marked decline in the emissions of air toxics, except for the aldehydes but when their weighting factors are applied, the weighted air toxics emissions from ethanol are below those of petrol. For comparison, the weighted emissions for diesel exhaust are estimated to range from 37,000 to 80,000 grams sulfuric acid equivalent per lifetime.

Table 13.9
Lifetime exhaust emissions (g) of air toxics from petrol and ethanol, along with weighted toxic emissions (grams sulfuric acid equivalent)

	Benzene	1,3-butadiene	Formaldehyde	Acetaldehyde	Aggregate toxics
Petrol	1820	210	350	126	2506
CMU-ET weighted	1138	48	389	0.4	1575
E85	252	28	574	3472	4326
CMU-ET weighted	158	6.4	638	9.6	812

Ethanol fuels perform better than conventional fuels in terms of lower emissions of air toxics, except for aldehydes.

13.6 Environmental Issues

Environmental and ESD issues related to ethanol have been dealt with in Chapter 6. Ethanol is not persistent in the environment. Virtually any environment supporting bacterial populations is believed to be capable of biodegrading ethanol. Atmospheric degradation is also expected to be rapid.

When ethanol is derived from a renewable source than the greenhouse gas emissions from ethanol are lower than those of petrol because of the use of a renewable fuel in the blend. The particulate emissions are lowered as are the emissions of ozone precursors. The concentrations of emitted air toxics are lower from ethanol than from petrol.

13.7 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

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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 13.10 lists the estimated emissions factors for ethanol. The columns in bold represent the standards relative to the Euro2 standard. The adjacent column gives the expected performance of ethanol. The estimates of Arcoumanis (2000) indicate that ethanol can be expected to meet all future Australian Design Rules for all pollutants, except for hydrocarbon emissions.

Table 13.10
Estimated emission factors for ethanol (E85P) under future technologies (PM is unregulated)

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		0.5	1.0	0.3
Euro3	1.05	0.9	0.59	0.8	0.6	0.5		0.5	1.0	0.25
Euro4	0.45	0.3	0.29	0.4	0.32	0.3		0.4	1.0	0.2

13.8 Summary

13.8.1 Advantages

- As a renewable fuel, anhydrous ethanol made from bio-products, produces less fossil CO₂ than conventional fuels.
- Tailpipe emissions of NOx and PM appear to be lower on average.
- Air toxic levels (except for aldehydes) are lower than those of conventional fuels.

13.8.2 Disadvantages

- Cold starting in cool climates is difficult unless ethanol is blended with petrol as a starting aid, or unless some other starting aid is used.