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Article

The Health Impacts of Ethanol Blend Petrol

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Abstract: A measurement program designed to evaluate health impacts or benefits of using ethanol blend petrol examined exhaust and evaporative emissions from 21 vehicles representative of the current Australian light duty petrol (gasoline) vehicle fleet using a composite urban emissions drive cycle. The fuels used were unleaded petrol (ULP), ULP blended with either 5% ethanol (E5) or 10% ethanol (E10). The resulting data were combined with inventory data for Sydney to determine the expected fleet emissions for different uptakes of ethanol blended fuel. Fleet ethanol compatibility was estimated to be 60% for 2006, and for the air quality modelling it was assumed that in 2011 over 95% of the fleet would be ethanol compatible. Secondary organic aerosol (SOA) formation from ULP, E5 and E10 emissions was studied under controlled conditions by the use of a smog chamber. This was combined with meteorological data from Sydney for February 2004 and the emission data (both measured and inventory data) to model pollutant concentrations in Sydney's airshed for 2006 and 2011. These concentrations were combined with the population distribution to evaluate population exposure to the pollutant. There is a health benefit to the Sydney population arising from a move from ULP to ethanol blends in spark-ignition vehicles. Potential health cost savings for Urban Australia (Sydney, Melbourne, Brisbane and Perth) are estimated to be A$39 million (in 2007 dollars) for a 50% uptake (by ethanol compatible vehicles) of E10 in 2006 and $42 million per annum for a 100% take up of E10 in 2011. Over 97% of the estimated health savings are due to reduced emissions of $PM_{2.5}$ and consequent reduced impacts on mortality and morbidity (e.g., asthma, cardiovascular disease). Despite more petrol-driven vehicles predicted for 2011, the quantified health impact differential between ULP and ethanol fuelled vehicles drops from 2006 to 2011. This is because modern petrol vehicles, with lower emissions than their older counterparts, will make up a higher proportion of the fleet in the future. Hence the beneficial effects of reductions in particulate matter become less significant as the fleet as a whole produces lower emissions.

Keywords: ethanol; health impacts; automotive emissions

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1. Background

In 2005 the Australian Government's Biofuels Taskforce reported that the environmental and human health impact of using ethanol as a biofuel was a major issue requiring resolution in order to guide national policy measures aimed at reducing greenhouse gas emissions. Issues highlighted were (i) potential changes in particulate matter (PM) emissions from ethanol blended petrol; (ii) changes in secondary particle formation as a result of exhaust and evaporative emissions; (iii) assessments of such emissions under Australian conditions, and once such changes had been established; (iv) quantification of health costs and benefits of the introduction of ethanol blended petrol in Australia.

Commencing in March 2007 a five-part study was undertaken to determine emissions from light-duty petrol vehicles using petrol, a 5% blend of ethanol in petrol (E5), and a 10% blend of ethanol in petrol (E10). The work program consisted of:

(1) Measuring Exhaust Emissions
(2) Measuring Evaporative Emissions

(3) Quantifying Secondary Particle Formation
(4) Impacts of E5 and E10 on Photochemical Smog
(5) Health Impacts of E5 and E10

The experimental results were applied to an air pollution model to evaluate the impacts of E5 and E10 on photochemical smog. Finally, the experimental results and modelling results were used to calculate the health impact of using E5 and E10. The detailed results of the study (including individual vehicle results) are available from the Australian Department of Environment Water Heritage and the Arts web site [1] and in [2] and [3].

Adding such small quantities of ethanol to petrol increases the vapour pressure, thus increasing evaporative emissions. The oxygen in the ethanol alters the combustion characteristics of the fuel leading to a different chemical profile of tailpipe emissions.

The concentration of an air pollutant provides an approximate measure of the dose of an air pollutant inhaled by an individual. It is an approximate measure because individuals vary in the frequency of inhalation and the volume inhaled. Individuals also move around so that their dose is related to the spatial distribution of the concentrations to which they have been exposed. The relationship between the dose of an air pollutant and the health impact is quantified using a dose-response relationship.

The exposure of an individual represents the accumulated dose arising over a period of time. The population exposure is the exposure calculated for the entire population subjected to the pollutant present within the airshed.

2. Method

The measurement program was designed to examine vehicles representative of the current Australian light duty petrol vehicle fleet. This was achieved by choosing vehicle makes and models with highest representation in the Australian fleet, ethanol suitability and emissions control system. A representative sample of 21 vehicles from the Australian passenger vehicle fleet were selected based on the above criteria for emissions testing. All vehicles were tested for exhaust and a subset were tested for evaporative emissions. The vehicles were tested over a composite urban emissions drive cycle (CUEDC) for light duty vehicles [4], which consisted of four phases—residential cold start, arterial, freeway and congested. The ADR79/01 test protocol was used for measurement of diurnal and hot soak evaporative emissions. Measurements were made for total hydrocarbons, carbon monoxide, oxides of nitrogen, methane, carbon dioxide, nitrous oxide, carbonyl volatile organic compounds, and air toxics such as 1,3-butadiene and ozone precursor hydrocarbons. The speciation of over 100 VOC compounds was determined. Particle analysis focussed on particulate matter of 2.5 microns diameter ($PM_{2.5}$), whilst measurements were also made to determine overall particle size and number concentration. $PM_{2.5}$ includes particulate mass below 2.5μm diameter, measured gravimetrically.

Exhaust emissions were examined for volatile organic compounds and air toxics, whilst the CSIRO smog chamber facility was used to simulate the photochemical processes and the formation of ozone and secondary organic aerosol (SOA) for the emissions that are specific to E5 and E10 blended fuels.

The vehicle emission data (exhaust and evaporative) were used to determine the quantity and types of pollutants. Data from this study were combined with inventory data for Sydney to determine the expected fleet emissions for Sydney. Additionally, the particulate matter (PM) data in the inventory were updated with preliminary results from the NISE2 study [4]; setting the level for petrol vehicles at 5mg/km for the period between 1994 and 1998. Fleet ethanol compatibility was estimated to be 60% for 2006, and for the air quality modelling it was assumed that in 2011 over 95% of the fleet would be ethanol compatible. The distance and the type of roads vehicles travelled were calculated as Vehicles Kilometres Travelled (VKT) and used in the modelling.

The results of the measurement programs and the smog chamber studies were then used in air quality modelling studies. Using actual meteorological conditions, with projected vehicle fleet numbers and emission factors the airshed conditions for given usage of E5 and E10 blended fuels in Sydney were simulated. Results were also extrapolated to Melbourne, Brisbane and Perth.

Meteorological and emissions data were combined to model the development of SOA and photochemical smog as well as other criteria pollutants such as particulate matter and nitrogen dioxide. Meteorological data from Sydney for February 2004 were combined with emission data (both measured and inventory data) to model pollutant concentrations in Sydney's airshed for 2006 and 2011. These concentrations were combined with the population distribution to evaluate population exposure to the pollutant. The results obtained from the air quality modelling in the Sydney airshed were used to estimate the quantified health impacts (measured in potential health cost savings) of using up to ten per cent ethanol blended with petrol.

3. Summary of Testing Results

3.1. Measurement of Exhaust Emissions

Vehicle tailpipe emissions showed that $PM_{2.5}$ emissions are reduced by operation on ethanol blends (Figure 1). The PM reduction with ethanol blends was often statistically significant for individual vehicles. The PM emissions when operating on ULP generally increased with accumulated vehicle mileage, with many of the vehicle model pairs in the test fleet showing this behaviour. In absolute terms the PM emissions when operating on ULP over the cold start CUEDC drive cycle were generally found to be below 5mg/km (the limit set for Euro5 diesel and direct injected petrol passenger vehicles).

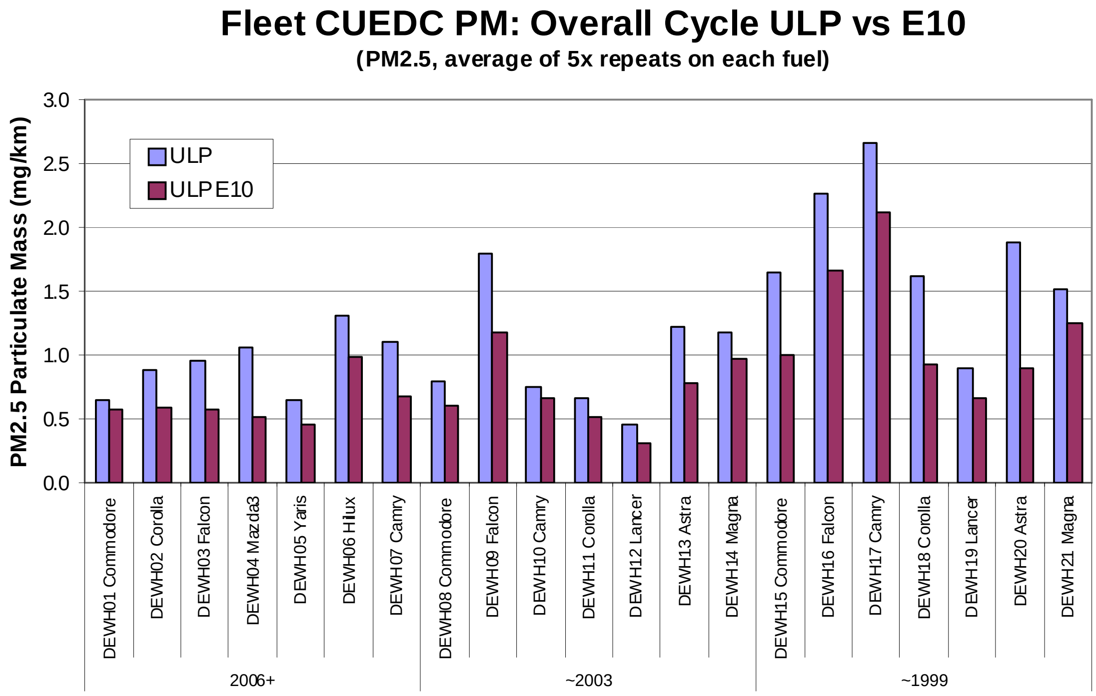
$PM_{2.5}$ emissions from the tailpipes of 2006+ model year vehicles that were tested showed a 19% decrease when using E5 and a 33% decrease when using E10.

Particle size and particle distribution data suggest that approximately 94% of the PM emissions are present as $PM_{2.5}$, and approximately 85% as PM1.

The effects of ethanol blends on regulated emissions—total hydrocarbons (THC) and carbon monoxide (CO) generally follow the well-established trend for the use of an oxygenated fuel, such as ethanol blended fuels. THC and CO emissions usually decrease with increases in ethanol content, whereas NOx emissions do not show such a clear trend [1].

The major carbonyl emissions were formaldehyde and acetaldehyde. Formaldehyde stayed the same or increased for individual vehicles, with some indication of an overall upward trend as the ethanol content of the fuel blend was increased. Acetaldehyde emissions were seen to increase significantly as the ethanol content of the fuel blend increased. A 3-fold higher fleet average emissions rate was observed for E10 compared to ULP. This is consistent with other studies that report little or no change in formaldehyde and significant increases in acetaldehyde for low ethanol blends [5–7].

Figure 1. Comparison of emissions of $PM_{2.5}$ for vehicles using ULP and E10 when tested under the Composite Urban Emissions Drive Cycle (CUEDC).



The BTEX, 1,3-butadiene and styrene air toxic emissions generally trend downwards with increases in the ethanol content of the fuel, as did the ozone precursor hydrocarbons. There are some vehicles for which the trends are inconsistent, or for which the change is not significant, particularly where the emissions rate is extremely low as is the case for styrene. These emissions are dominated by the vehicle's after-treatment performance in the cold start part of the CUEDC. As a result, the trends are easier to observe if the cold start results are examined; particularly for the older vehicles where the catalyst has shown signs of degradation.

The measured level of alcohol emissions from the vehicle exhaust was at very low levels. Generally the older vehicles emit ethanol, and some also emit methanol, with either E5 or E10 fuel blends and these increase with the ethanol content of the fuel. The emission of methanol may be a result of poor combustion, or the presence of richer than stoichiometric combustion during warm-up on some of these older vehicles. Whilst some newer vehicles emit ethanol when running on the E10 blend, the level of emission from the newer vehicles was very low compared to the older vehicles.

3.2. Measurement of Evaporative Emissions

The vehicle evaporative emissions testing shows that THC emissions follow the vapour properties of the fuel. The addition of ethanol to the base ULP affects the vapour pressure, and volatility of the blend. Fuels with small quantities of ethanol, such as E5 and E10, have a higher volatility than the base ULP to which the ethanol is added. The absolute value of the volatility of low ethanol blends is sensitive to the base chemistry of the ULP fuel to which it is blended. As expected, when mixed with the base ULP stock used in this study, the E5 blend had a higher vapour pressure than the E10 blend. As such, the THC emissions of vehicles tested with E5 are seen to be higher than those when tested with E10, with ULP giving the lowest emissions. In relative terms, E5 generally leads to at least a doubling of the evaporative THC emissions, whilst E10 emissions are 50% higher than with ULP. These trends are similar to other studies.

Each Australian vehicle emission standard is determined by an Australian Design Rule (ADR). At the time of this study, petrol and LPG vehicles had to comply with the ADR 79/01 certification test, which introduced Euro3 emission standards for light vehicles. The ADR79/01 evaporative test used in this study consisted of a 24 h diurnal breathing loss test (the diurnal phase representing the emissions released due to the effect of ambient temperature change) and a 1-hour soak test. The diurnal phase is seen to dominate the total evaporative emissions typically making up 80–95% of the total.

All the newer vehicles designed to ADR79/01 meet the legislated limit of 2.0g/test with ULP. Newer vehicles, with one exception, also emit less than 2.0 g/test when tested with the ethanol blends. These results were recorded for a fuel with a volatility (DVPe) for ULP of ~63kPa, representative of typical Australian summer grade fuel.

Evaporative BTEX emissions are also seen to follow the trend in fuel volatility and are aligned to THC results. Total BTEX results are generally highest for E5 (consistent with E5 having the highest volatility), followed by E10 with ULP having the lowest.

Evaporative emission of alcohols was influenced by individual vehicle factors that are likely to depend on the design of the vapour canisters of the vehicles. Vehicles with smaller canisters compared to fuel tank capacity struggled to control evaporative emissions when tested with the ethanol blends, whilst vehicles with larger canisters were better able to accommodate the increase in vapour. New vehicle results also appear affected by artefact emissions which are hypothesised to be remnants from the manufacturing process such as glues and solvents which may have alcohols present. The results for the older vehicles have no such artefacts, suggesting that by the time the vehicles are eight years old these remnants have volatilised.

Detailed test results may be found in [1].

3.3. Secondary Organic Aerosol

Although particulate matter is emitted directly from vehicle exhaust, evaporative and exhaust emissions of VOC can also produce particulate matter through the production of secondary organic aerosols (SOA). SOA formation was modelled during the air quality modelling phase of the project on the basis of experimental results from the CSIRO smog chamber.

Smog chamber experiments were performed for four tests: (1) Evaporative emissions from ULP, E5 and E10 for both fully evaporated fuel and equilibrated headspace vapour (2) Combustion, or tailpipe, emissions for ULP, E5 and E10 for both 'cold start' and 'hot running' (idle) conditions.

Chemical modelling of the smog chamber data for both ozone and SOA was shown to reproduce the data to an acceptable level of accuracy.

The scaling factor required to match the model predictions of SOA formation to the smog chamber data was shown to be constrained to a relatively small range. The models for ozone and SOA were subsequently used in the air quality section with the scaling factor for SOA as developed from the experimental data.

3.4. Impacts on Photochemical Smog

The smog chamber results were incorporated into the detailed chemical kinetic Carbon Bond 2005 model (CB5) [8] to enable the SOA component of the air quality models to be optimised. A three-dimensional weather and air pollution modelling system known as TAPM-CTM [9,10] was used to investigate the potential changes from the use of ethanol-blended fuel by the Australian fleet by considering the Sydney motor vehicle fleet as a representative sample. The airshed modelling task consisted of two components: (1) evaluate the potential changes in ozone; (2) assess the relative change in population exposure for ozone, nitrogen dioxide, carbon monoxide and $PM_{2.5}$.

Figure 2 shows how the E5/E10 scenarios impact on the modelled NEPM exceedence statistics for ozone. Figure 2a and b show the modelled spatial distribution of the daily frequency of 1-hour O_3 > 100 ppb for the ULP_2006 and ULP_2011 emission scenarios. It can be seen that the highest frequency in a given model cell (three exceedence days during the simulated month) occur to the south west of Sydney. It can also be seen that there is a reduction in the number of exceedences for the ULP_2011 emission scenario compared to the ULP_2006 scenario. Summing the exceedence frequencies for all of the 60 × 70 model cells shown in Figure 2a and b gives a domain total number of exceedence cell-days of 697 for ULP_2006 scenario and 410 cell-days for the ULP_2011 scenario, or 41% fewer than the 2006 scenario. The lower result for ULP_2011 is due to the reduced level of emissions from the 2011 vehicle fleet.

Figure 2c and d show how the cumulative number of exceedence days changes for the E5/E10 emission scenarios. It can be seen that the number of cell-days increase by about 1.4% for the 50E10 scenarios, by 2.8–3.0% for the 100E10 scenarios, and by 3.0–4.6% for the 100E5 scenarios.

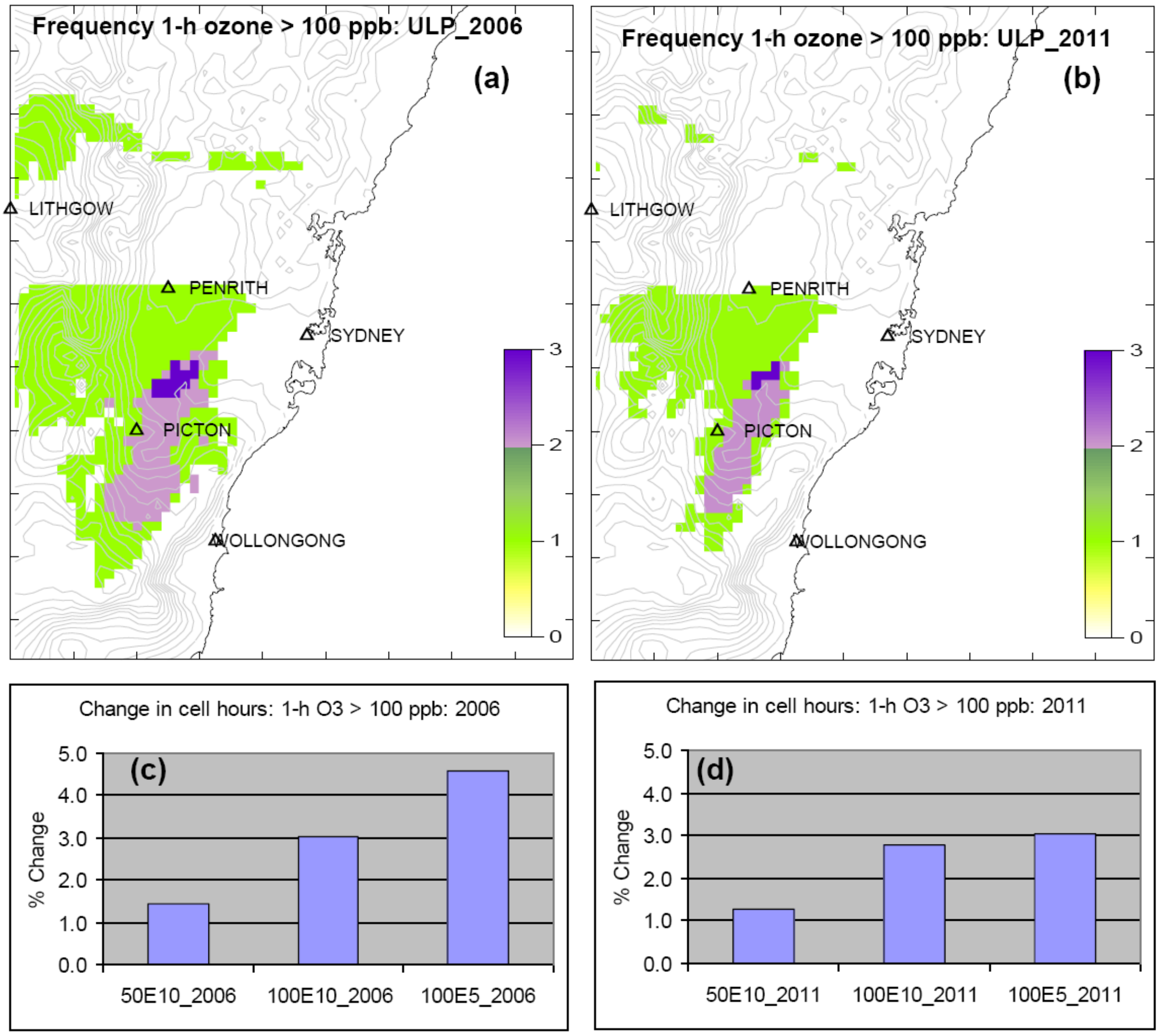
The modelled concentration fields of the criteria pollutants (CO, NO_2, PM-including secondary organic aerosols, O_3), were used to generate population exposure statistics that were then used to estimate the change in health impacts according to the following four step methodology:

1. Calculate 1-hour average (the native averaging time of TAPM-CTM) pollutant concentration fields for O_3, NO_2, CO and $PM_{2.5}$ for an E5/E10 scenario and for the corresponding ULP baseline scenario.
2. Generate multi-hour average concentration fields as appropriate for the health assessment.
3. Using the prescribed concentration thresholds and a population data base for Sydney, calculate the relative health impact metrics.
4. Use the metrics generated in step 3 to scale an existing peer-reviewed health impact assessment for Sydney for each of the criteria pollutants.

Further details of the formulae used are given in [1]. The results obtained from this process are shown in Figure 3.

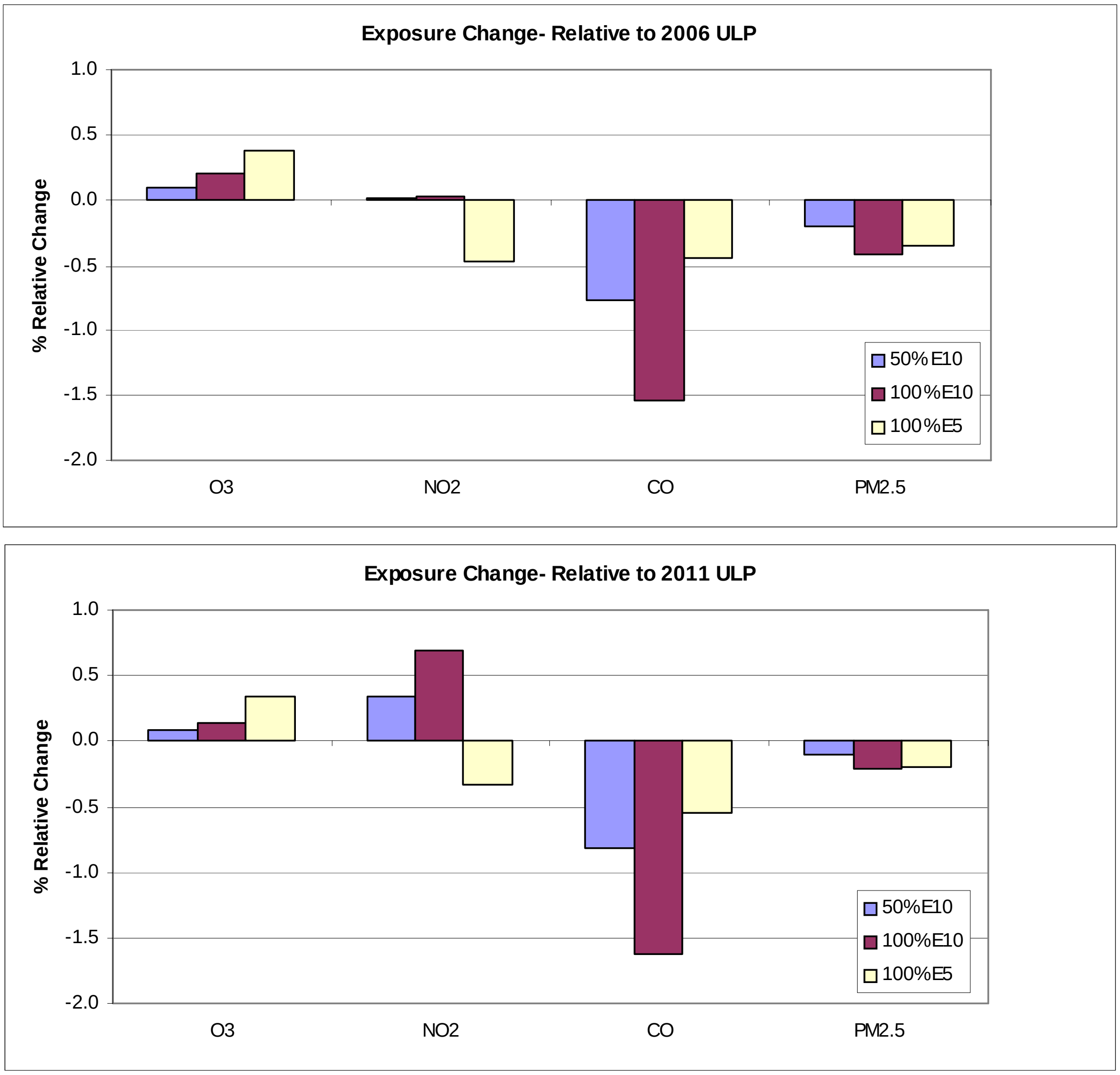
Small increases in peak ozone concentrations were observed for all of the E5/E10 emission scenarios. This implies that the observed reduction in the tailpipe mass emissions of VOC and CO were not sufficient to cancel out increases in the evaporative VOC mass emissions associated with the higher vapour pressure of the blended fuels compared to ULP. The typical scale of increase in peak 1-hour ozone concentrations (typically of the order of 100 ppb) was 1 to 2 ppb for E10 and 2 to 4 ppb for E5.

Figure 2. Impacts of the modelled ethanol scenarios on 1-hour ozone statistics for Sydney (**a**) Daily number of exceedences for 1-hour ozone concentration >100 ppb for the one month simulation using the ULP_2006 motor vehicle inventory; (**b**) As for (**a**) but using the ULP_2011 inventory; (**c**) Percentage relative change in the number of exceedence cell-days when using the 2006 ethanol inventories; (**d**) As for (**c**) but using the 2011 inventories.



In all cases the magnitude of the modelled population exposure change was 2% or less. Increases in population exposure were seen for ozone for all E5/E10 scenarios and for nitrogen dioxide for the E10 scenarios. A decrease in exposure was predicted for $PM_{2.5}$ for all scenarios and for nitrogen dioxide for the E5 scenario.

Figure 3. Modelled relative change in population exposure for 2006 (top) and 2011 (bottom) emissions scenarios.



4. Health-Impact Basis

The exact way in which the health impacts are calculated differs for various pollutants. Overall, the calculations used a three-step "baseline-increment" method. The three-steps are:

1. Determine the baseline health impact associated with the particular pollutant being examined. If these are available from a recent official Australian Government Publication then those baselines will be used. If not then the baselines need to be calculated.
2. (a) In the case of air toxics, determine the increment or decrement to the baseline emissions as a result of the use of E5, and as a result of the use of E10 on the basis of the experimental results obtained from this study; (b) In the case of particulate matter and criteria pollutants, determine the increment or decrement to the baseline exposure (which is calculated as the population-weighted airshed concentration) as a result of the use of E5, and as a result of the use of E10 on the basis of the modelling results obtained from this study.

3. Having determined the increment or decrement to the baseline emissions or to the baseline exposure, this increment (or decrement) is applied to the baseline health impact to determine the change in health impact arising from the use of E5 and/or E10.

5. Value of a Statistical Life

Having determined the health impact, it is quantified by assigning dollar values to morbidity and mortality. The quantified cost of mortality is termed the value of a statistical life (VOSL). Amoako *et al.* [11,12] assumed the value of a statistical life to be $1.3 million whereas the Ambient Air Quality NEPM [13] assumed $7 million, a value that has also been recommended in a recent study [14]. This latter value of $7 million was used.

6. Health Impact Results

The overall finding is that there is a health benefit to the Sydney population arising from a move from ULP to ethanol blends in spark-ignition vehicles. Based on the average fleet make up in 2006 this value is approximately $16 million for a 50% uptake (by ethanol compatible vehicles) of E10 and is $17 million per annum for a 100% take up of E10 in 2011. The main reason for the diminishing increase in benefit in 2011 compared with 2006 is because of the already low particle emissions from the petrol vehicle fleet which declines even more by 2011 as newer lower emitting vehicles enter the fleet. Potential health cost savings for Urban Australia (Sydney, Melbourne, Brisbane and Perth) are estimated to be $39 million for a 50% uptake (by ethanol compatible vehicles) of E10 in 2006 and $42 million per annum for a 100% take up of E10 in 2011. The major contributor to the health benefits was the reduction in particle emissions when using E5 or E10.

Quantified health impacts, as in Table 1, are based on one month of modelling in the Sydney airshed (February), scaled up to represent a full year as well as a full year's modelling for 2006 for the 100% E5 scenario, which assumes that all cars that are capable of using E5 do so.

6.1. Particulate Matter (PM)

6.1.1. Baseline

The Impact Statement for $PM_{2.5}$ Variation [13] sets the baseline for health impacts in Australia on the basis of Sydney, Melbourne, Brisbane and Perth. The health impacts in terms of the number of people affected annually are given in Table 5-4 of the NEPM document.

ABS data give the population for Sydney in 2001 as 4,128,272 and as 4,284,379 in 2006. The population of Sydney, Melbourne, Brisbane and Perth (which we refer to as Urban Australia) in 2001 was 10,220,931 people and 11,368,662 in 2006. Using these values yields the values in Table 2 for Sydney and for Urban Australia, to which have been added the 95% confidence intervals of Burgers and Walsh [15].

NEPC [13] contains health costs associated with hospital admissions for asthma ($8,875), cardiovascular disease ($11,709) and chronic obstructive pulmonary disease (COPD, $9,610) in 2001 dollars. Adjusted to 2007A$ using CPI inflation values this results in $10,447 for asthma, $13,783 for cardiovascular disease and $11,312 for COPD.

Table 1. Total Quantified Annual Health Impact changes of Ethanol over ULP for $PM_{2.5}$ Mortality and Morbidity (2007A$millions, 90% CI) based on monthly and annual simulations.

Location	**2006 Results (Based on February)**			**2006 Annual Run**	**2011 Results (Based on February)**		
	50% E10	**100% E10**	**100% E5**	**100% E5**	**50% E10**	**100% E10**	**100% E5**
Sydney	−15.7 (−5.5 to −32.5)	−31.0 (−10.8 to −64.1)	−25.2 (−8.7 to −52.1)	−22.7 (−5.4 to −50.6)	−7.85 (−2.7 to −16.2)	−16.8 (−5.8 to −34.7)	−15.3 (−5.3 to −31.6)
Urban Australia *	**−38.5 (−13.3 to −78.8)**	**−75.8 (−25.9 to −155)**	**−61.6 (−21.4 to −127)**	**−55 (−13 to −122)**	**−19.5 (−6.7 to −40.0)**	**−41.6 (−14.3 to −85.5)**	**−37.9 (−13.1 to −77.8)**

* Sydney, Melbourne, Brisbane and Perth.

Table 2. Health effects (number of people affected) for 2006 attributable to levels of $PM_{2.5}$ in Australia.

Area	**Short Term Health Endpoint**						**Long Term Health Endpoint**		
	Mortality			**Hospital Admissions**			**Mortality**		
	All cause	**Respiratory**	**CV**	**Asthma**	**Cardio-vascular**	**COPD**	**All cause**	**Lung Cancer**	**COP D**
Sydney	286	85	57	164	257	61	729	92	550
95% CI Low	163	52	8	64	152	13	250	28	191
95% CI High	406	119	105	262	361	113	1291	142	932
Urban Australia *	701	214	140	333	574	103	1770	214	1205
95% CI Low	402	132	20	130	345	21	614	67	424
95% CI High	1001	299	261	536	816	196	3178	337	2071

* Sydney, Melbourne, Brisbane and Perth.

It should be noted that the agreed Australian baseline value for particulate matter is based on $PM_{2.5}$ concentrations. This means that quantified health effects are based on the $PM_{2.5}$ data collected during the vehicle experiments documented in CSIRO and Orbital Engine Corporation [1].

6.1.2. Increment

The above baseline values and the results of the population exposure modelling were applied to four different scenarios for Sydney for 2006 and 2011. The four scenarios are ULP (100% of the petrol-driven vehicles running on ULP, which is taken as the baseline), 50% E10, 100% E10 and 100% E5 (note that the percentages indicate the proportion of the ethanol-ready fleet that is assumed to use ethanol blends, not the percentage of the total fleet; viz. 60% in 2006 and 95% in 2011). The time periods are (1) vehicle emissions in 2006, based on records of registered vehicles in Sydney; and (2) vehicle emissions for 2011, based on projections for uptake in newer vehicles with reduced emissions (due to better technology and adherence to new Australian emissions standards), and corresponding retirement of older vehicles. 2011 costs have also been increased slightly to account for the expected population change between 2006 and 2011.

The values in Table 1 show the annual differences in health costs for the scenarios and time periods compared to that of 100% of the petrol-driven vehicles using neat ULP (based on the month of February) and for a run of the model for the entire year. Negative values indicate a benefit, *i.e.*, savings in health costs (in millions of 2007A$) as a result of reduced $PM_{2.5}$ emissions. These values have then been scaled up for Urban Australia on a population ratio basis. Values in parentheses are the 90% confidence intervals as used by NEPC [13] (rather than the 95% confidence intervals used by Burgers and Walsh [15]).

Over 99% of the $PM_{2.5}$ health costs are due to reductions in short and long term mortalities. Short term mortalities arise from respiratory illnesses, long term mortality from cancers. Morbidity costs due to asthma, cardiovascular disease and COPD make up only about 0.1% of the overall health costs.

Despite there being more petrol-driven vehicles and a higher population predicted for Sydney and Urban Australia in 2011, in most cases the quantified health impact differential between ULP and ethanol fuelled vehicles drops from 2006 to 2011. This is because modern petrol vehicles, due to increasingly stringent emissions standards, emit measurably less emissions than their older counterparts, and will make up a higher proportion of the fleet in the future—hence the beneficial effects of reductions in particulate matter with the use of ethanol become less significant as the fleet produces lower emissions as a whole.

Similar calculations were undertaken for the other criteria pollutants and for air toxics. Because the health impacts are dominated by particulate matter, they are not reported in this paper but are available on line [1].

7. Discussion

Table 3 provides a summary table of indicative annual total baseline health cost increases for Urban Australia based on the sum of all criteria pollutants and air toxics previously mentioned, based on the month of February, and for the averaged entire year. The health costs due to mortality from particulate matter dominate the baseline health costs and are over fifty times the quantified health impacts from air toxics, the next largest health benefit. Thus it is believed that indicative health costs for other blends of ethanol in ULP could be performed in the future by measuring comparative $PM_{2.5}$ emissions.

All of the totals in Table 3 are negative, indicating savings; even though the ozone component of the total indicates disbenefits. There was a total of $20 million for a 50% take-up of E10 in 2011, in 2007A$ for Urban Australia. This contrasts with the results of Jacobson [16] who found that E85 may cause more harm than ULP due to its similar cancer risk but enhanced ozone health risk, and increased PM2.5 and PM10 emissions. Beer and Grant. [17] also assumed that particulate matter emissions would not decrease as a result of the use of ethanol in vehicles, but the testing results reported in this paper, and in more detail in CSIRO and Orbital Engine Corporation [1] indicate that particulate matter emissions decrease when ethanol blends are used in the present-day Australian vehicle fleet.

Due to the introduction of newer vehicles whose emissions are expected to be lower, the savings resulting from a 100% uptake of an ethanol blend are expected to drop in the future. The use of an ethanol blend in 2011 is expected to yield mean health cost benefit values ranging from a savings of $20 million to $42 million for Urban Australia, allowing for a projected overall increase in population and vehicle numbers.

The values in Table 3 indicate that the quantified health benefits in 2011 are less than those in 2006. The reason for the lower health benefits in 2011 is that the newer vehicles emit less PM so that the relative benefit of PM reduction is reduced.

Table 3. Indicative Summary Table of Increases in Annual Baseline Health Cost (2007$millions, 90% Confidence Intervals) for Urban Australia *.

Urban Australia	**2006 Results (Based on February)**			**2006 Annual Run**	**2011 Results (Based on February)**		
	50% E10	**100% E10**	**100% E5**	**100% E5**	**50% E10**	**100% E10**	**100% E5**
PM Mortality	−38.466	−75.853	−61.663	−55.594	−19.497	−41.600	−37.899
PM Morbidity	−0.0305	−0.0602	−0.0490	−0.0441	−0.0155	−0.0330	−0.0301
Ozone	0.1412	0.2985	0.5798	0.3874	0.1309	0.2400	0.5623
Nitrogen Dioxide	0.0004	0.0008	−0.0189	−0.0182	0.0145	0.0289	−0.0139
Air Toxics	−0.6239	−1.2176	−0.2838	−0.2838	−0.5067	−1.011	0.0320
Total	**−38.979**	**−76.831**	**−61.435**	**−55.553**	**−19.874**	**−42.375**	**−37.349**
90% CI	−13 to −81	−27 to −159	−21 to −127	−13 to −124	−7 to −41	−15 to −88	−13 to −78

* Sydney, Melbourne, Brisbane and Perth.

The baseline-increment method is based on two key assumptions. The first assumption is that variations in loads and concentrations are sufficiently small that it is appropriate to linearise the responses. This is expected to be valid given that the change from ordinary petrol (that is itself a variable mixture of many different constituents) to E10 is that of slightly altering the petrol mixture. The second assumption is that the response ratio is the same as the increment ratio. This is liable to be valid for air toxics, PM, ozone, and NO_2 for which it is believed that there is no threshold concentration. It is less likely to be the case for CO which has a threshold for health effects but as it eventuated, all CO concentrations measured as part of this study, and modelled for the future scenarios, indicate that CO concentrations will lie below the threshold so that there will be no health impacts arising from CO for either ULP or ethanol blends.

The procedure adopted in this report to quantify the health effects of the use of ethanol in petrol provide a tractable methodology that utilises agreed baseline values, and measured variations from the baselines. It is inevitable that further scientific progress will lead to refinements of the methodology. In particular, there is considerable attention now being paid to the role of PM_1, and particle number distributions in health effects. Until such studies yield agreed dose-response relationships from which baseline health effects can be calculated, we are unable to utilise the data in quantified health-effects calculations.

In relation to health cost differences, 97% of these are due to mortality differences arising from particulate matter with the quantified health costs being based on the value ascribed to the VOSL. The overall value of the benefit of using ethanol blends over ULP will vary if the calculations were based upon a VOSL value that is significantly different to the value of A$7 million that is used in this report. This figure of A$7 million is based on its use by the Ambient Air Quality NEPM and we have confirmed it by a review of the related literature and re-analysis of the data.

The overall conclusion, that ethanol blends have a slight health advantage over neat ULP is true for VOSL values above $26,000. Such a value is much lower than the lowest recommended VOSL in studies [18] that have examined the subject, in which the lowest VOSL is set at US$700,000 (and the highest is set at $15.9 million).

8. Conclusions

This study estimates that there is a health benefit to Sydney and the Urban Australian population (taken as Sydney, Melbourne, Brisbane and Perth) arising from a move from neat ULP to ethanol blends in spark-ignition vehicles. Based on the average fleet make-up in 2006 this value for Sydney is approximately $16 million for a 50% take-up of E10, (based on the results for February; for an average annual run of the model the value for a 100% take-up of E5 is approximately $23 million in 2006). For Urban Australia the 2006 values are approximately $39 million for a 50% take-up of E10 (based on the results for February; for an average annual run of the model the value for a 100% take-up of E5 is approximately $56 million in 2006).

The overall quantified health benefit of using ethanol blends is overwhelmingly dominated by reductions in particulate matter.

Although sensitivity analysis reveals that these values can vary significantly, the overall conclusion in respect of a health benefit is robust.

The benefits reduce with time as newer vehicles enter the fleet. For 2011 it is estimated that the quantified health benefits for Sydney are approximately $8 million for a 50% take-up of E10, $15 million for a 100% take-up of E5, and $17 million for a 100% take-up of E10. For Urban Australia the corresponding values are approximately $20 million for a 50% take-up of E10, $37 million for a 100% take-up of E5, and $42 million for a 100% take-up of E10.

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