ATTACHMENT C

Draft Final Report on the Project to Estimate the Emissions Impacts and Cost Effectiveness of the Adoption of Euro 3 Emission Standards

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For the

Motor Vehicle Environment Committee

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Introduction

This report is the delivery of a contract to the Federal Office of Road Safety. Earlier work undertaken by the author had been incorporated in the ACVEN report into the review of ADR-37/01 as part as an SAE submitted report. This earlier work had examined the impact of six scenarios of possible emission standards on the passenger car emission source input into the Melbourne airshed. This work had excluded examination of the European Year 2000 standard commonly known as Euro 3.

This report extends to the earlier work to include Euro 3 projections and cost benefit analysis.

Objectives

The objective of this project is to obtain reliable estimates of the emissions and cost effectiveness of the adoption in Australia of Euro3 Standards relative to Euro2 and US EPA Tier 1 Standards.

Scenarios

The following four scenarios will be embodied in the presentation of emissions projections and the cost effectiveness of the following scenarios:

Introduction of US Tier 1 Emission Standards for All New Passenger Cars from 2002

Introduction of Euro2 Emission Standards for All New Passenger Cars from 2002. It will be seen that this objective evolved into 2 scenarios.

Introduction of Euro2 Emission Standards for All New Passenger Cars from 2002 followed by the Introduction of Euro3 Emission Standards for all New Passenger Cars from 2006

Introduction of Euro3 Emission Standards for All New Passenger Cars from 2002

Emission Standards

The following Table 1 identifies the ADR37/00 & 001 Standards as well as the ECE Euro 2 and Euro 3 Standards. It should be restated that the test procedure for the Euro procedures is different from that for ADR37. In addition it should be noted that there is a variation in the procedure between Euro 2 and Euro 3 in including the first forty seconds of engine operation in Euro 3 which is omitted in Euro 2. The significance of this will have particular consequence to HC and CO emissions and to a lesser extent on NOx and almost no impact on fuel consumption. This is because emissions produced during the starting and warm up period are included in the Euro 3 measurement process, as they have always been included in the ADR37 procedure.

Table 1 Regulated and proposed emission standards

	HC g/km	CO g/km	NOx g/km
ADR 37/00	0.91	9.4	1.93
ADR 37/01	0.25	2.11	0.63
Euro 2	0.25*	2.2	0.25*
Euro 3	0.2	2.3	0.15
Euro 4	0.1	1.0	0.08

* Assumed split, HC + NOx = 0.5

Emissions Projections for Melbourne

Conversion Factors

An extensive search of the published literature has been undertaken to identify if there are possible conversion factors that are relevant to the present task. The search has been both library sourced and Internet based. All of the references were found in US and European literature, apart from the recently produced FORS project data. However, there are issues of vehicle type and size mix being different in Europe and the US from Australia. It would be fair to say that with respect to the specific task of conversion factors for ECE/US FTP, the only data that was found in the search was an SAE paper written by Environment Canada, and subsequent investigation revealed that this was based on the ECE15, rather than Euro 2, test cycle that includes the extraurban driving cycle. Other data is available in documents provided by industry and testing agencies using European or Japanese market cars.

By delaying the submission of this report by one week it has been possible to increase the FORS data base from the 5 car test data used in the interim report to that for 19 cars (however only 16 were used). It is this data base that was judged to be the most relevant for the task of these projections because:

- the cars were ones sold into the local market
- the data were obtained on the same equipment at the Ford Emission laboratory used in part of the baseline study (see below)
- the raw data were available for error checking if questionable results were found

In addition to establishing conversion factors for Euro 2 to US procedures on which ADR37 has been based, there has been an endeavour to relate production vehicle performance in Euro 2 specification to Euro 3 performance to determine the effect of the change in test procedure.

The data base used by the author in preparation of the 1997 SAE's submission to ACVEN was based on measurements made to ADR37 on vehicles tested by the various EPAs and from the FORS 600 car study (FORS, 1996). The range of conversion factors from Euro 2 (ECE 94/12) to ADR 37 test method are found in Table 2

Table 2 ECE Euro 2 to ADR 37 conversion factors

	HC	CO	NOx	HC +NOx

JAMA	1.612	1.69	1.28	1.41
FCAI	1.48	1.56	1.05	
ACEA		1.40		1.32
FORS 16 cars	1.632	1.271	1.330	

The data used in the 1997 SAE projections for Euro 2 were those provided by JAMA.

Discussion of Euro 2 to Euro 3 conversion factors

There are five major differences between the Euro 2 and the Euro 3 standards:

- the values of allowable emissions as given in Table 1
- the inclusion of emissions in Euro 3 from engine cold start. (In Euro 2 there is a pre-test 40 second idle which is eliminated in Euro 3)
- a production conformity requirement.
- an OBD (on board diagnostic) requirement.
- more stringent evaporative emission procedure.

The second point not only has a major influence on the emissions quantity, the deliberate exclusion of cold start emissions has an influence on environmental impact.

In the analysis which follows, these excluded emissions are included in the estimation of the air-shed inventory of car emissions in the following way:

Euro 3 is taken as the base Euro case. Euro 2R (R = real) is introduced which:

- factors in the excluded amounts, since they are emitted to the environment, and
- allows for the difference in the values required by the standard as given in Table 1 assuming that HC = NOx for Euro 2 as suggested in the table.

Table 3 Ratios of Alternative test cycles to ADR 37 and Euro 3 to Euro 2

	HC	CO	NOx
Euro 2/ADR 37*	1.639	1.271	1.330
PREVIOUS Eu2 (JAMA)	1.612	1.690	1.280
Euro 3/ADR 37*	2.034	2.071	1.571
AUC/ADR 37*	2.157	2.898	1.668
Euro 3/Euro 2*	1.241	1.629	1.181
Eu3/Eu2 (UK data source)	1.227	1.725	1.227

* from FORS data (Source private communication from Jon Real)

The current 19 car FORS data is summarised in Appendix A. By reducing this data set to 16 cars, all able to comply with ADR 37/01 and Euro 2 as tested the outlier cars were eliminated as described in the Appendix.
It can be seen that the Euro3/Euro2 compares favourably with a UK confidential source of data.
These data are presented graphically in figure 1.

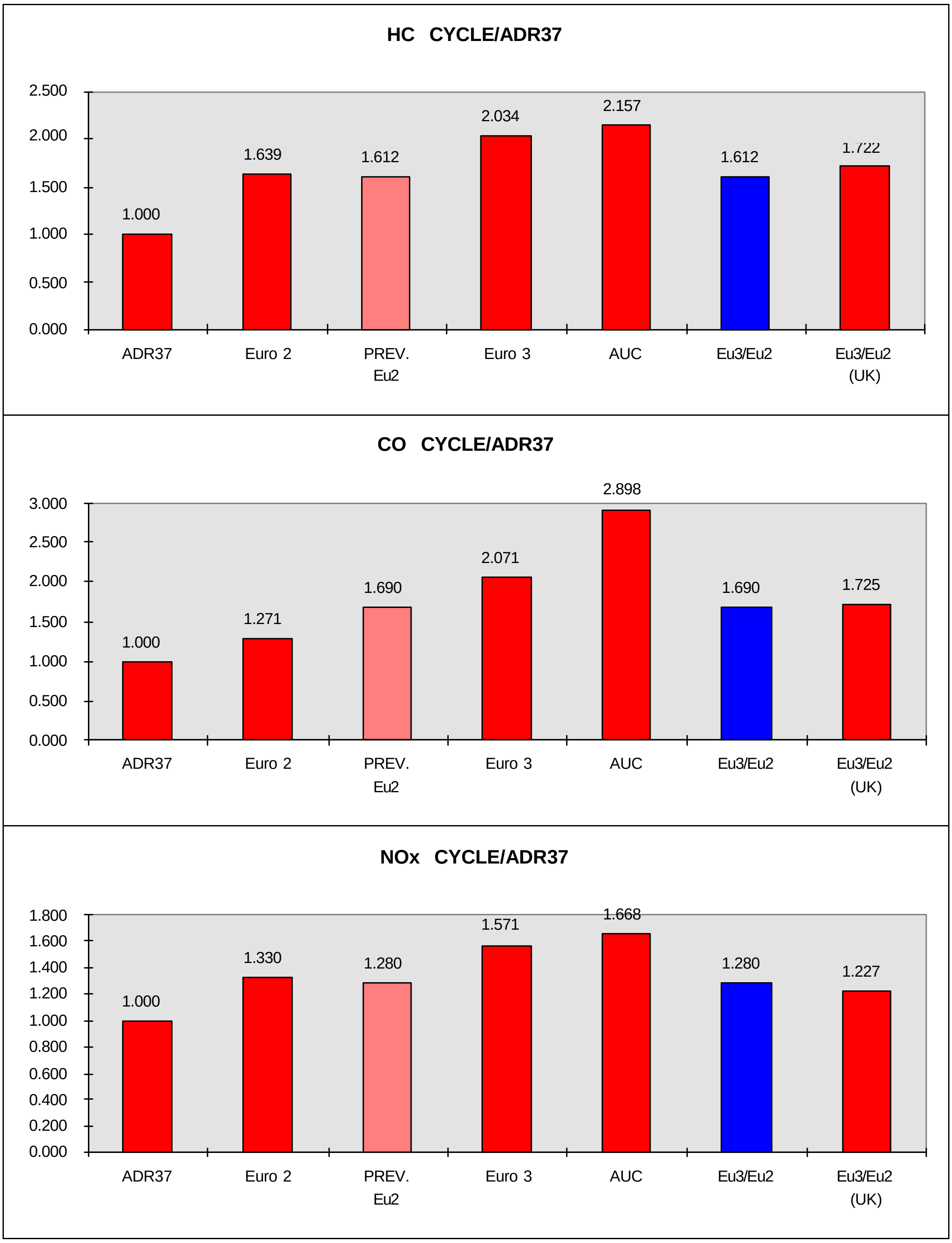

Figure 1 Drive cycle ratios for 16 car data set.

<u>In Service Performance</u>

The simulations carried out here make assumptions about the deterioration slope of the in service vehicles. This can be described as the initial emission rate of the new vehicle and the emissions rate at the 80,000km certification point for the test procedures. Based on the Australian 600 car study data obtained from the FORS report in the submission to ACVEN (SAE report) it was argued by sensitivity analysis that an initial emission rate of 0.5 times the standard and a rate at 0.9 times the standard at

80,000km were conservative values. Only one of the scenarios examined in the sensitivity analysis had a slightly higher emissions rate than this scenario.

It follows that in this work it has been assumed that Euro 2 vehicles would emit according to the 0.5 - 0.9 factors and that Euro 3 vehicles would do slightly better (a 20% reduced deterioration (based on Californian experience)) because of the OBD facilitating repair of emission defective systems. It has been suggested that the deterioration of Euro 2 emissions may be faster than ADR37/00. However, it is the authors view that the industry would continue to be inherently conservative about catalyst loadings and the like, since it would not wish to be caught in a major recall program if there was to be shown a consistent failure of its emission systems. This is evidenced by the fact that in the ADR37/00 vehicles surveyed by FORS in the 600 car study, there were only 4 vehicles that required catalyst replacement.

If however the 0.5 - 0.9 factors are not acceptable further work could be undertaken with different factors.

There is an additional issue that needs to be considered: as mentioned above, the Euro 2 test omits the first forty seconds of engine operation in the exhaust gas analysed. This omitted gas contains high concentrations of HC and CO as the cold engine is started. This omission may be explained as compensation for later hot restarts of the engine in real-world conditions, but not included in the test procedure. From the environmental standpoint, it is the cold start, in the 6 to 10 am period that is most influential in providing photochemical smog precursors. Therefore, this forty seconds should be included in emissions inventory calculations, either entirely or partially (if some proportion of hot starts is to be included). As explained in Appendix A this can be done with only small approximation by correcting the Euro 2 estimated car emission data by a Euro 3/Euro 2 factor for each pollutant. This scenario is called Euro 2R (R= real). In the source projections which follow, the entirely cold start scenario is included for the Euro 3 implementation in 2002.

Projections of Car Emissions in the Melbourne Airshed

The calculation of emissions within a given region or airshed is an established method. It involves for each vehicle in the fleet, calculating its emissions, allowing for deterioration in performance with distance travelled, and estimating: the change in annual distance driven with age; the difference in emission rates from the standard test expected in-service; the probability of the vehicle being scrapped from the fleet during the course of a particular year's operation; and the introduction of new vehicles into the fleet to new owners and to replace those scrapped. The details of the method are presented in Appendix B and this is supported by a graphical representation in figure B.1 of the process which shows the general trends of the variables used in the calculation and their dependence upon year or distance driven by the vehicle.

There are some limitations of this method since they calculate the global input into a given region, in this case the Melbourne statistical district. It is possible that traffic congestion may cause the saturation of vehicle emission inputs into particular regions, thus limiting local emission source into areas which may be significant in the later-in-the-day pollution, for example, the formation of ozone. Also, it is possible that the growth of new suburbs in the city causes an extension of the corridors over which critical parcels of air pass, collecting the emissions that cause the ozone problem. In this simple analysis it is assumed that the city grows in a homogeneous way.

In addition to the uncertainties associated with the nature of the source area and distribution, just described, there are also other uncertainties of similar or greater magnitude, particularly the in-service deterioration performance already mentioned, the variability of vehicle sales according to the state of the economy, and the growth of population, and several other variables. Thus, it is the nature of any projection work that these uncertainties need to be recognised. With further effort sensitivity analysis can be undertaken to quantify the effects of likely variance in these parameters, but that is not part of the work delivered here.

Results

The graphs which follow in figures 2 to 4, for projections of the passenger car source of Melbourne's emissions, allow comparison of ADR37/01 with US Tier 1 implementation in 2002, Euro 2 (and Euro 2R) in 2002, and Euro 2R in 2002 followed by Euro 3 in 2006 and the last scenario, Euro 3 implementation in 2002. All Euro 3 simulations assume that the OBD effect is a 20% reduction in the rate of emission deterioration with age. This only has a small effect on the results by 2015 (of the order of 5 to 7% extra reduction). The results for the projections for year 2015 are summarized in Table 4.

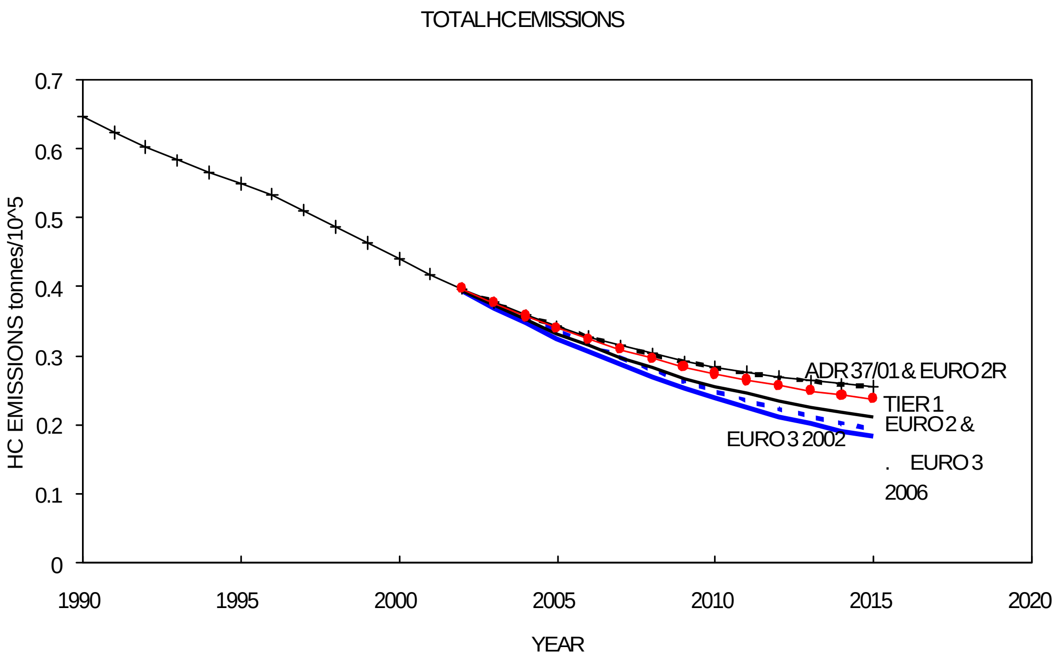

Figure 2 **Total (exhaust, evaporative and crankcase) HC projections for the Melbourne airshed.**

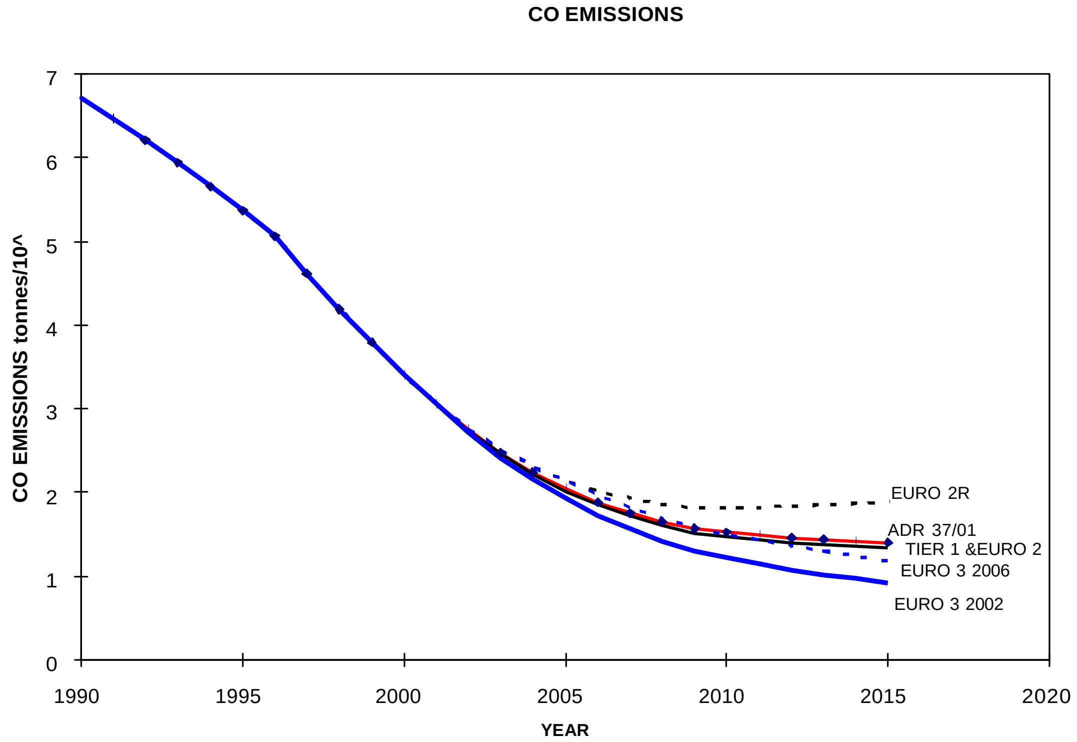

Figure 3 CO projections for the Melbourne airshed

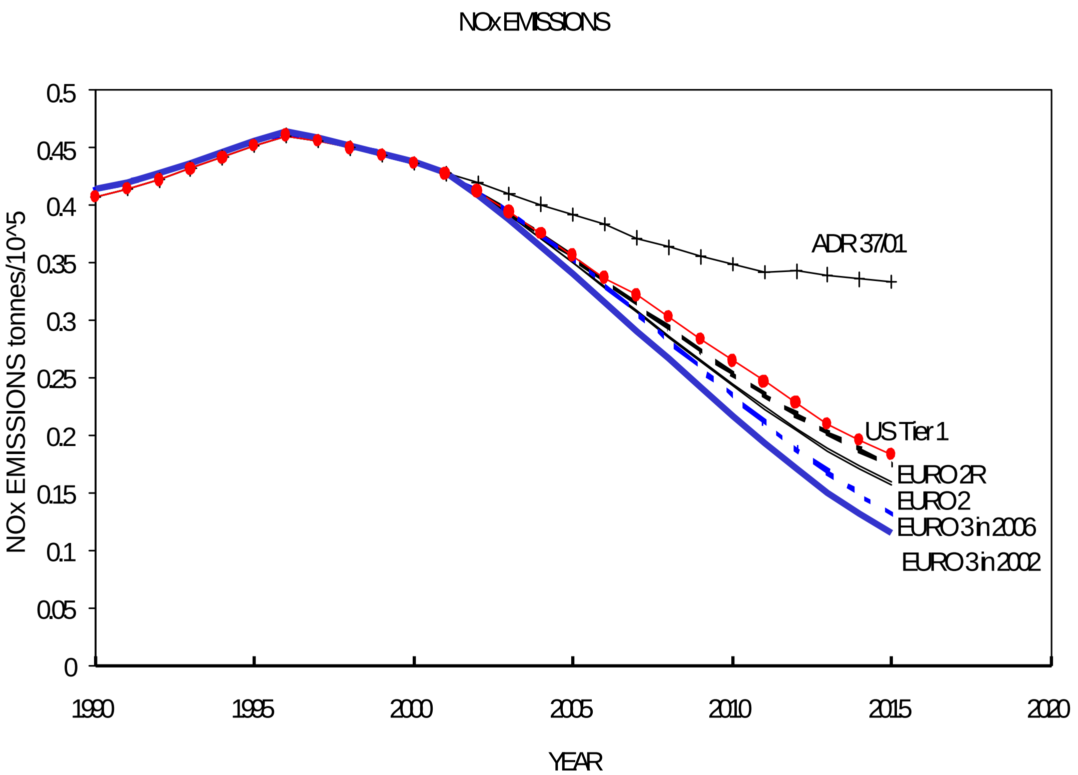

Figure 4 NOx projections for the Melbourne airshed.

Table 4 Projected values for the passenger car input to the airshed under four scenarios for the year 2015

	HC ktonnes	CO ktonnes	NOx ktonnes
ADR 37/01	25.50	1550	33.3
US Tier 1	23.71	1399	18.32
Euro 2 only in 2002	21.13	1389	15.61
Euro 2R (incl. 40 s) only in 2002	25.43	1884	17.43
Euro 2R in 2002 & Euro 3 in 2006	19.25	1176	13.06
Euro 3 in 2002	18.23	919	11.47

Euro 3 Cost Analysis

The cost analysis is performed in Appendix C. At the foot of Table C.2 there is found a relative narrow band of average costs of Euro 3 technology over that of Euro 2. It may be that the findings of the three European documents are interlinked by coming from a common source. However, costs from present development of Euro 3 technology for implementation next year seems to support the other reported values.

It is concluded that, excluding the costs of Euro 3 evaporative emission control requirements that an average price increment range of $300 to $700 will occur. This is added to the Euro 2 costs previously presented by the FCAI in their submission to ACVEN.

Table 5 Projected costs per new vehicle sold of the emission control options presented in $Aus

	ADR 37/01	US Tier 1	Euro 2	Euro 3	Euro 3 inc Evap
Low	0	500	350	725	775
High	0	650	500	1125	1200

These values have been used to compute the range of emission control costs presented in Table 6.

Summary Conclusions

Reported here is the process for obtaining estimates of the emissions source from petrol fuelled passenger cars and derivatives in Melbourne and the costs of the adoption of Euro3 Standards relative to Euro2 and US EPA Tier 1 Standards. The values of cost per mass emission reduction are presented in Table 6.

Table 6 Estimates of the cost per mass of emission reduced

	Scenario	US Tier 1	Euro 2	Euro 2R	Euro 2R/3 2006	Euro 3
m$/ktonne HC	Low	115	28	1893	41	36
	High	149	41	2704	62	55
m$/ktonne NOx	Low	12.4	7.13	7.96	11.69	12.13
	High	16.12	10.19	11.38	17.68	18.57
m$/(ktonne HC+NOx)	Low	11.19	5.7	7.93	9.09	9.08
	High	14.54	8.15	11.33	13.75	13.90

The emission reductions used for the Table 6 calculations are the cumulative emissions change for the period 2002 to 2015. This is a more accurate evaluation than using the emission in year 2015 alone. The incremental vehicle costs are the sum for all the vehicles sold in the period 2002 to 2015 inclusive (2.55 million).

In preparing Table 6 the range of costs from Table 5 and are assumed constant for the period. In the first four rows the costs are attributed to each tonne of the individual (HC or NOx) emissions reduced even though the same investment simultaneously reduced all emissions. As CO emissions are unlikely to be of concern in any Australian city they are excluded from this presentation. In the last two rows it has been assumed that HC and NOx are equally harmful and may be added without weighting factors.

The results show that scenario Euro 2 is likely to be the most cost effective of all the scenarios on a cost benefit basis. However, Euro 2 ignores emissions during the first 40s of engine operation. When corrected for this in Euro 2R scenario the cost for HC control is very high. However, in the combined HC + NOx analysis Euro 2R is more cost effective than either of the Euro 3 analyses.

The Euro 3 scenarios, Euro 2R in 2002 and Euro 3 in 2006, and Euro 3 in 2002, are equally cost effective, but more expensive than Euro 2R alone, particularly as judged by the combined HC + NOx values. If only NOx control is needed then the Euro 2R in 2002 and Euro 3 in 2006 scenario would be preferred.

The reader is reminded that the emission reductions forecast are strongly dependent on the use of US/ECE test conversion factors based on a small amount of data 16 cars from the current 50 car test program. Not only are the conversion factors important but the HC/NOx ratio has been assumed as 1/1 in the Euro 2 analysis, since the ECE regulation (directive) refers to emissions of HC+NOx of 0.5 g/km. The 16 cars tested do not have a 1/1 HC/NOx.

It is recommended that this report might be updated at the completion of the FORS test program and the presentation reworked using a more representative HC/NOx ratio.

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Appendix A

ANALYSIS OF 19 CAR FORS DATA

The in-progress test of 50 representative cars to various test cycles has been analysed at a time when the data for 19 cars was available (Private communication from Jon Real of FORS).

If valid comparison is to be made of the relative environmental impact of cars developed to different emission standards, an ideal experiment would include back-to-back tests of individual car models developed by the manufacturer to be compliant with each standard. It is unlikely that more than a few such models could be sourced from the world market. An alternative, but with some compromise would be to test vehicles that were compliant with both (ADR37/01 and Euro 2). ADR37/01 and Euro 3 comparison is unlikely to be relevant since Euro 3 is a much more stringent standard as specified in the standard's emission numbers and in real technical difficulty in compliance.

To date, only a few of the manufacturer's cars that have been tested in the FORS program have been sanctioned by the manufacturer as Euro 2 compliant, (as current models they are all ADR37/01 compliant with one exception - an ADR37/00 Ford Falcon). To proceed with this analysis, 16 cars have been selected as vehicles which meet both ADR37/01 and Euro 2. There were five cars that also met (marginally in some cases) Euro 3. All of these were imports.

The following tables show the 16 cars emissions rates, and the fraction of the emission standard. It is clear that the fleet average was well under (20 to 40%) the ADR37/01 standard, and at 47 to 70% of the Euro 2 standard,

Table A.1 16 car emissions to ADR 37 test

	HC	CO	NOx
Emissions g/km	0.08	0.81	0.13
Fraction of ADR 37/01 standard	0.30	0.39	0.21

Table A.2 16 car emissions to Euro 2 test

	HC	CO	NOx
Emissions g/km	0.12	1.03	0.17
Fraction of Euro 2 standard*	0.49	0.47	0.70

Assumes HC = NOx for standard

Table A.3 16 car emissions to Euro 3 test

	HC	CO	NOx
Emissions g/km	0.15	1.68	0.21
Fraction of Euro 3 standard	0.77	0.73	1.38

The assumption made in this work that all new cars meet 50% of ADR and Euro 2 standard rates is seen to be true for all emissions except Euro 2 NOx.

Appendix B

EMISSION PROJECTION METHODOLOGY

Mathematical formulation

Whilst there exist several methods for estimating the future demand for transport fuels or exhaust emissions it is usual to project the growth of cities (urban airsheds) or the country as a whole based on the expected population growth and to use vehicle ownership trends to estimate the likely vehicle population.

The growth of the vehicle population has been assumed to be represented by a non-linear relationship with time. This will vary from city to city depending upon vehicle ownership, the geographic location of the city in generating inter city travel by road, economic factors influencing discretionary travel and the availability of alternative transport means and so on. It has been found that for cars and derivatives in Australia this approach produces a simple time series relation.

For three Australian cities studied (Watson 1992), the relation for the population P of vehicles using fuel type j is of the form

$$P_j = (a + b*\text{year})^{0.5}$$

From a projection of the vehicle population growth, vehicle sales can be derived once data are provided on the car scrappage or the survival rate. Thus if the market for vehicle type j in model year i is N_{ij}, then those sold in that year will be:

$$n_{ij} = N_{ij} - N_{(i-1)j} + \underset{\text{all}_i}{\underline{\text{SUM}}} \{p_{iyj}\}$$

where n_{ij} is number of vehicles of type j sold in model year i

p_{iyj} is the proportion of vehicles made in model year i and scrapped in year y. Typically 25 historical years are included in the analysis for a current year.

The scrappage rates p_{iyj} are found from the Australian Bureau of Statistics Surveys of Motor Vehicle Use over the period 1971-1991. The form of these functions may be found in Appendix A of Watson (1991). The p_{iyj} functions are calculated on a regional basis e.g. the Melbourne Statistical District in this instance, and have been found to change with time as depicted in figure B.1 as the median age of the fleet has extended from 13.5 years in 1976 to 16 years in 1988. This trend is extrapolated into the future.

The equation for the emission of type e, or fuel consumption of the total vehicles of type j (cars or trucks) in year y is, from Watson et al. (1981):

$$F_{je} = \underset{\text{all}_i}{\underline{\text{SUM}}} \{n_{ij}.s_{iyj}.v_{iyj}.f_{ije}.c_{iyje}\}$$

where s_{iyj} is the proportion of vehicles of model year i not scrapped (i.e. surviving) by year y (= 1- p_{iyj})

v_{iyj} is the km of travel in year y by the vehicles of model year i

f_{ije} is the emission or fuel rate of the model year i

c_{iyje} is the correction factor for the difference between the measurement process according to ADR37 or AS2877 and real world emission or fuel consumption.

The form of the v_{iyj} with the age of the car may be found in Appendix A of Watson (1991), where it is shown that old cars travel less than half the distance per year covered by new ones. A sketch of the form of this relation found in figure B.1.

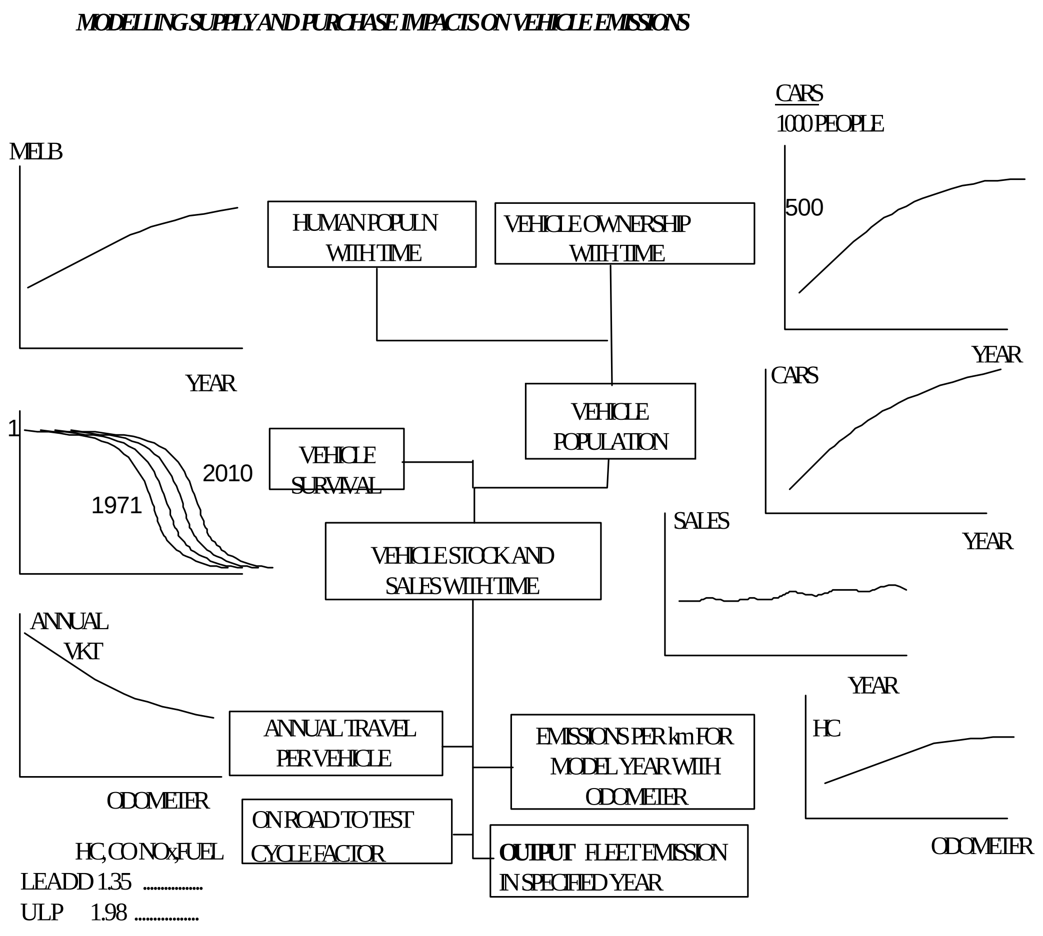

Figure B.1 Forms of the relationships used in the simulations

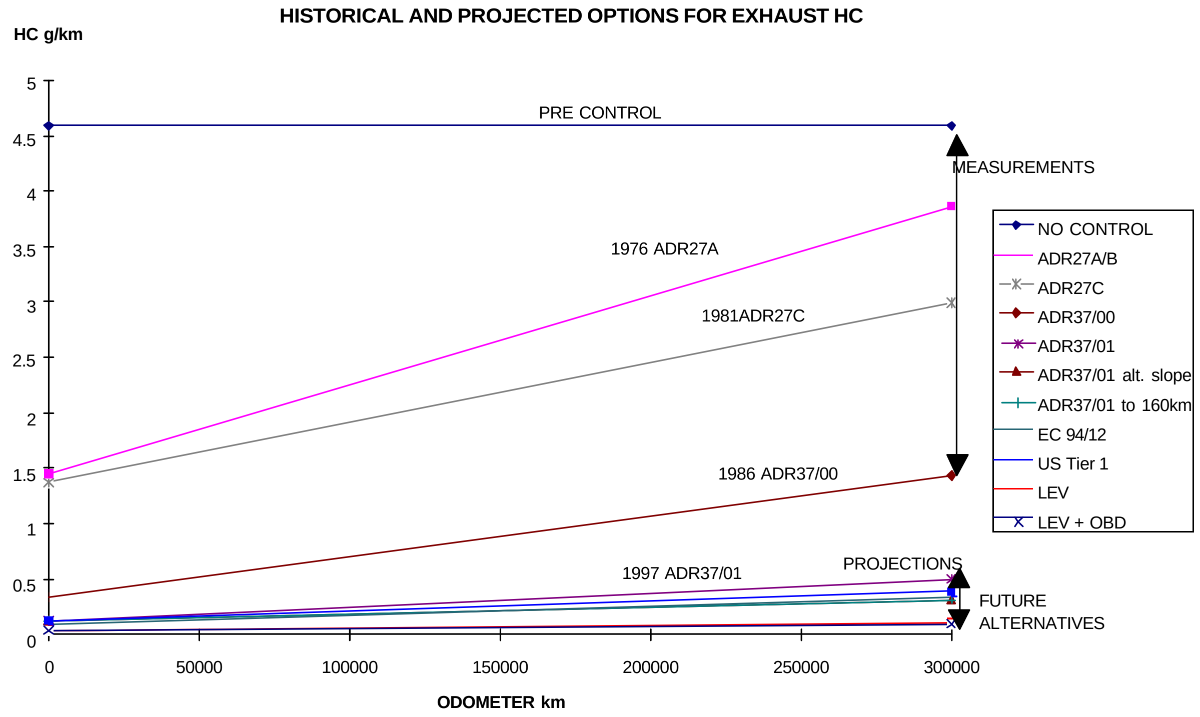

Figure B.2 Per vehicle HC emissions as measured for the historical fleet and predicted for the range of scenarios covered in the SAE Report (Watson, 1997) .

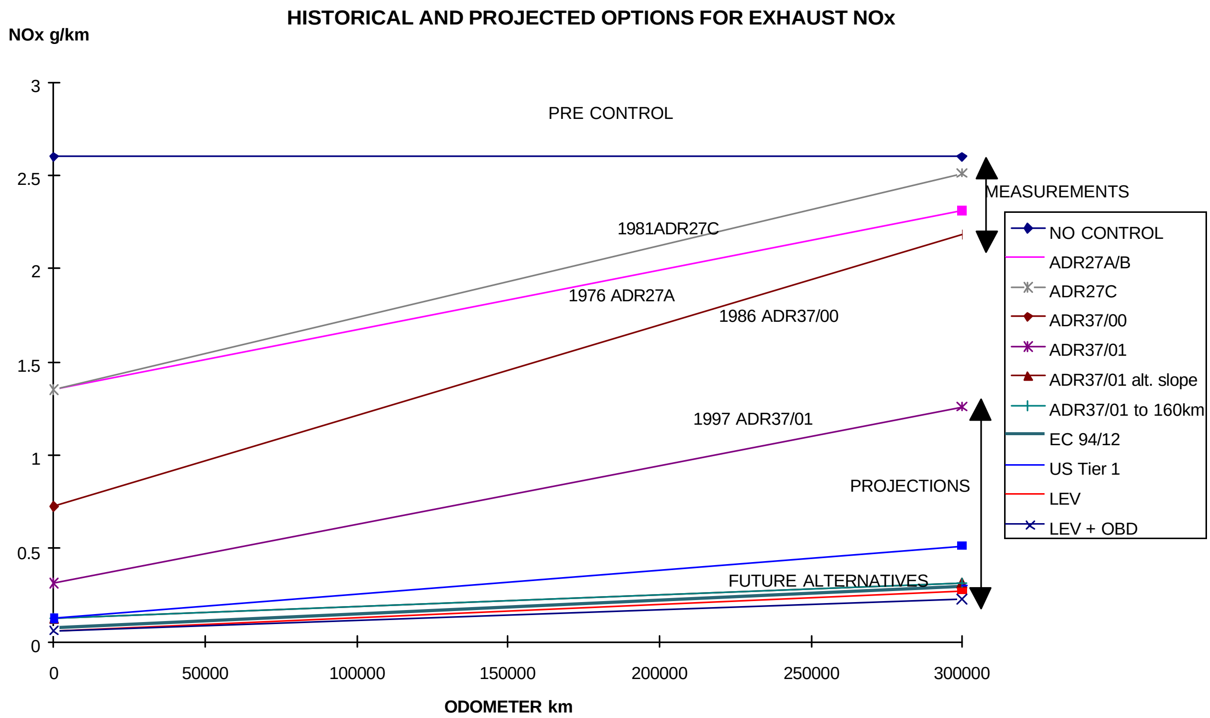

Figure B.3 Per vehicle NOx emissions as measured for the historical fleet and predicted for

Appendix C

EURO 3 COST ANALYSIS

The procedure adopted for determining the cost of moving from Euro 2 to Euro 3 has been to carry out a literature search of the available American and European databases, which reflect the published information in a number of journals and institutions. About 45 papers were extracted from this literature search of which 8 were obtained. However, although potentially there was information on the effect of changing technology none of the cost data presented yielded values that were suitable for the present study in which it would be desirable to reflect the Euro 2 and Euro 3 cost penalty across several vehicle classes.

The data that have been useful have been obtained by other means. Primarily from data supplied by FORS, and the author's personal contacts, in Europe.

Table C.1 Data extracted for large (upper medium) car conversion costs to various levels of emission reduction from a Euro 1 base, converted to $Aus

	Touche - Ross Study (1995)	
	Scenario 2	Scenario 3
Item (N.B. multiples of some needed)	Approx Euro 2	Approx Euro 3
Improved electronic engine control	4	6
Exhaust gas recirculation (EGR)	39	38
Improved and low light-off wash coats	9	19
Greater catalyst loading	9	19
Dual oxygen sensors	54	54
Improved fuel preparation and injection	37	61
Auxiliary air injection	73	73
Air assisted injectors	15	15
Double wall exhaust pipes	9	9
Close coupled catalyst	110	
Heated catalyst		292
Research and development	131	309
Business support (included in above)	23	43
Total	**490**	**896**

The analysis of each of these data sets is presented leads to the tables which follow. It must be stated at the outset that most of these values are speculative, since a lot of the Euro 3 technology is new and not yet introduced into production. There is also the assumption that the adoption of more mature technology, by later implementation (Euro 2 in 2002 instead of 1996 or Euro 3 in 2002 or 2006 instead of 2000) will not incur cost reductions. This may be counteracted by the transport, small volume issues in Australian implementation. Tariff and import duty considerations are also ignored.

The Touche Ross study was carried out in 1994 and not completed until the end of 1995, before Euro 2 was implemented. Thus it identifies the need for a heated catalyst to meet Euro 3. It is probable that the development of storage and low temperature light-off catalysts will have over taken the heated technology. Nonetheless, many of the items listed in would appear to be relevant in the author's opinion.

Table C.2 Compilation of various sources of European conversion costs leading to values of the Euro 3 to Euro 2 costs in $Aus

Source		Touche Ross Study					
		Scenario 2	Scenario 3		CEC Commn	EPEFE	Priv. Comm
CAR		Approx Euro 2	Aprrox Euro 3	Euro 3-Euro 2	Euro 3 - Euro 2	45-65%	Euro 3 - Euro 2
Small	Industry min	375	759	384			
	Industry max	668	1848	1180			
	Average	526	1131	605	357	423	
	Estd package	368	608	240			
	OBD		147	147			
	Evaporative		59	59			
Medium	Industry min	146	363	217			375
	Industry max	885	1471	586			525
	Average	507	1025	518	402	457	
	Estd package	386	622	236			
	OBD		147	147			
	Evaporative		63	63			
Large	Industry min	300	613	313			
	Industry max	1018	2763	1745			
	Average	633	1212	579	518	609	
	Estd package	490	896	406			
	OBD		173	173			
	Evaporative		69	69			
Weighted	Industry min	299	621	322			375
40/20/40	Industry max	851	2139	1287			525
	Average	565	1142	**577**	**430**	**504**	**450**
	Estd package	420	726	**306**			
	OBD		157	157			
	Evaporative		64	64			

Table C.2 is largely self explanatory. The weighting of small/medium/large cars of 40/20/40 is introduced as a rough representation of the Australian market split. The estimated package costs represent a build up from lists as in Table C.1 (including R&D etc) for the various vehicle size classes, whereas the industry values were their reported estimates, on average about 80% higher than from the parts base. How various overheads were included by industry in their estimates appears to have been a cause of some of the difference.

These data suggest that \$450-550 is about the average from the various sources. We note that OBD and evaporative emission components are not included in the estimated package value which is for exhaust emission control alone. Whilst the benefit from OBD is included in the Euro 3 simulations in this report the evaporative emission control benefit is not. The cost of this is seen to be estimated to be more than \$50. This leads to the view that an average increase of \$500 without evaporative controls is likely. Noting that the weighted average industry minimum is about \$300 a variance of +/-\$200 seems probable. The industry high values of \$1300, probably reflect costs on complex vehicles with smaller volume runs and whilst noticed, is ignored in the range of expected costs of \$300 to \$700 for Euro 3 over Euro 2.