NSW GOVERNMENT

Advisory Committee
on Tunnel Air Quality

TP01:
Trends in Motor Vehicles and their Emissions

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1. Summary

- Australian new vehicle emission standards are set nationally in the Australian Design Rules (ADRs), and have been progressively and significantly improved over the last 40 years.
- The National Fuel Quality Standards have progressively required cleaner fuels to complement the ADRs and enable use of improved emission control technology.
- Emissions from the in-service vehicle fleet (ie the vehicles we drive in NSW) has significantly reduced as a consequence of the more stringent emission standards and cleaner fuel.
- Vehicle kilometres travelled (VKT) are increasing steadily, with passenger vehicle VKT increasing in line with population growth at around 1% annually, while freight vehicle VKT is growing in line with economic growth at 2–3%. annually
- In spite of the increase in VKT, the strong reduction in vehicle emission rates has resulted in significant reductions in the total fleet emissions, and these reductions are projected to continue over the next 10–20 years.
- Heavy duty diesel vehicles, and in particular rigid trucks, are disproportionate contributors to exhaust particulate matter emissions.
- As the newer vehicles in the fleet have significantly reduced emissions due to the tighter ADRs, the older vehicles in the fleet built to earlier less stringent standards, make a significant and disproportionate contribution to the total fleet emissions.
- Fleet composition in terms of both vehicle type and age classes are important factors determining the level of emissions from any specific road corridor.

2. National Vehicle Emission Standards

New on-road motor vehicle emission standards are set by the Commonwealth Government via the Australian Design Rules (ADRs). The first ADR governing vehicle emissions was set in 1972 with ADR26, which set a limit for the exhaust concentration of carbon monoxide (CO) at idle. This was followed by ADR27 in 1974 which introduced standards based on mass of emissions per kilometre (grams per kilometre – g/km) measured under a transient drive cycle designed to represent urban driving conditions. The first emission standard for diesel vehicles was set in 1976 under ADR30/00 with the adoption of United Nations Economic Commission for Europe Regulation 24/00 which set limits for exhaust opacity (smoke) under steady state loaded conditions.

The emission standards for light and heavy duty vehicles have been progressively tightened over time based variously on United States and European Union (EU) standards. The current light duty vehicle emission standards are approximately 20-30 times lower than the original drive cycle based standards in force in 1976, while current heavy duty diesel standards are 4 times lower for oxides of nitrogen (NO_x) and more than 10 times lower for particulate matter (PM) than those first introduced in 1995. In addition to the reduction in emission limits, the required durability of emission controls has been significantly extended.

The history of Australian standards for petrol passenger cars, diesel passenger cars and heavy duty diesel engines is summarised in Table 1, Table 2 and Table 3 on the following pages. Charts displaying the ADR's are included in Appendix A[1]. For passenger cars Australia has adopted the latest European standard, Euro 6, although the implementation date lags Europe by around 3–4 years. For heavy duty engines it is currently proposed to adopt Euro VI in 2017, which also lags Europe by four years. Europe has not formally proposed stricter future standards. The US have recently brought in Tier 3 standards for light duty vehicles which by 2025 will be around 80% more stringent for NO_x + hydrocarbons (HC) than Euro 6, whilst possibly less stringent for PM.

1 More detailed information on the ADRs may be found at **http://www.infrastructure.gov.au/roads/environment/index.aspx**

Table 1: Petrol Passenger Car Emission Standards (grams per kilometre)

ADR	Standard	Date[1]	CO	HC/ NMHC[2]	HC+NO_x	NO_x	PM[3]	PN[4]	Test Cycle
ADR27A[5]		Jul 1976	24.2	2.1/–	–	1.9	–	–	US FTP 72
ADR37/00	US'75	Feb 1986	9.3	0.93/–	–	1.93	–	–	US FTP 75
ADR37/01	US'90	Jan 1999	2.1	0.26/–	–	0.63	–	–	US FTP75
ADR79/00	Euro 2	Jan 2004	2.2	–/–	0.50	–	–	–	ECE + EUDC
ADR79/01	Euro 3	Jan 2006	2.3	0.20/–	–	0.15	–	–	NEDC
ADR79/02	Euro 4	Jul 2010	1.0	0.10/–	–	0.08	–	–	NEDC
ADR79/03	Euro 5	Nov 2013[6]	1.0	0.10/0.068	–	0.06	0.0045[7]	–	NEDC
ADR79/04	Euro 5	Nov 2016	1.0	0.10/0.068	–	0.06	0.0045[7]	–	NEDC
ADR79/05	Euro 6	Jul 2017	1.0	0.10/0.068	–	0.06	0.0045[7]	$6x10^{11}$[8]	NEDC

(1) Standard applies to all vehicles built after this date, generally applies to new models 1 year earlier.

(2) Non-methane hydrocarbons.

(3) PM particulate mass.

(4) PN (particle number) per km.

(5) ADR27A was the first introduction of g/km limits for carbon monoxide (CO), hydrocarbons (HC) and NO_x.

(6) Applies to new models only.

(7)(8) PM & PN standards apply to petrol direct injection engines only.

2. National Vehicle Emission Standards

Table 2: Diesel Passenger Car Emission Standards (grams per kilometre)

ADR	Standard	Date[1]	CO	HC/ NMHC[2]	HC+NO_x	NO_x	PM[3]	PN[4]	Test Cycle
ADR70/00	Euro 1	Jan 1996	2.72	–	0.97	–	0.14	–	ECE + EUDC
ADR79/00	Euro 2	Jan 2003	1.0	–	0.70/0.90[5]	–	0.08/0.10[5]	–	ECE + EUDC
ADR79/01	Euro 4	Jan 2007	0.50	–	0.30	0.25	0.025	–	NEDC
ADR79/02	Euro 4	Jan 2010[6]	0.50	–	0.30	0.25	0.025	–	NEDC
ADR79/03	Euro 5	Nov 2013[7]	0.50	–	0.23	0.18	0.0045	–	NEDC
ADR79/04	Euro 5	Nov 2016	0.50	–	0.23	0.18	0.0045	$6x10^{11}$	NEDC
ADR79/05	Euro 6	Jul 2018	0.50	–	0.17	0.08	0.0045	$6x10^{11}$	NEDC

(1) Standard applies to all vehicles built after this date, generally applies to new models 1 year earlier.
(2) Non-methane hydrocarbons.
(3) PM particulate mass.
(4) PN (particle number) per km.
(5) First limit applies to indirect injection engines, second applies to direct injection engines.
(6) Same standard as ADR79/01 (Euro 4) but extends to more vehicle classes.
(7) Applies to new models only, applies to all vehicles from ADR79/04.

Table 3: Heavy Duty Diesel Emission Standards (grams per kilowatt-hour)

ADR	Standard	Date[1]	CO	HC/ NMHC[2]	NO_x	PM[3]	PN[4]	Test Cycle
ADR70/00	Euro I	Jan 1996	4.5	1.1/–	8.0	0.36	–	ECE-R49
ADR80/00	Euro III	Jan 2003	2.1/5.45[5]	0.66/0.78	5.0/5.0	0.10/0.16	–	ESC/ETC
ADR80/02	Euro IV	Jan 2008	1.5/4.0	0.46/0.55	3.5/3.5	0.02/0.03	–	ESC/ETC
ADR80/03	Euro V	Jan 2011	1.5/4.0	0.46/0.55	2.0/2.0	0.02/0.03	–	ESC/ETC
ADR80/04[6]	Euro VI	Jan 2017	1.5/4.0	0.13/0.16	0.4/0.46	0.01/0.01	$8x10^{11}$/ $6x10^{11}$	WHSC/ WHTC

(1) Standard applies to all vehicles built after this date, generally applies to new models 1 year earlier.
(2) Non-methane hydrocarbons.
(3) PM particulate mass.
(4) PN (particle number) per kilowatt-hour.
(5) First limit applies to ESC test cycle, second to the ETC cycle.
(6) Proposed.

3. National Fuel Standards

Complementing the progressive tightening of the vehicle emission standards, the national fuel standards have also been revised to reduce vehicle emissions in several ways:

- Specifications which support the implementation of new emission control technology (eg elimination of lead in petrol and reductions of sulfur levels in fuel to enable the use of exhaust catalysts);
- Specifications to directly reduce engine-out (ie before exhaust catalyst) emissions (eg reductions in benzene concentrations in petrol);
- Reduction of petrol volatility to reduce evaporative fuel emissions.

Fuel specifications have in general been aligned to European fuel standards to match the requirements of vehicle technology designed to the EU emission standards adopted in Australia. Key fuel specifications are detailed in Table 4 for petrol and Table 5 for diesel[2].

Table 4: Key petrol fuel standard specifications

Property	Standard	Fuel Grade	Implementation Date
Sulfur	≤500 ppm	unleaded petrol	1 Jan 2002
	≤150 ppm	premium unleaded petrol	1 Jan 2002
	≤150 ppm	All	1 Jan 2005
	≤50 ppm	premium unleaded petrol	1 Jan 2008
Benzene	≤1% by vol.	All	1 Jan 2006
Lead	≤0.005 g/L	All	1 Jan 2002
Olefins[1]	18% pool av. over 6 months; 20% cap	All	1 Jan 2004
	≤18% by vol.	All	1 Jan 2005
Aromatics[1]	45% pool av over 6 months; 48% cap	All	1 Jan 2002
	42% pool av over 6 months; 45% cap	All	1 Jan 2005
Reid Vapour Pressure[2]	62 kPa from Nov to March	All	Nov 2004[3]

(1) Pool average over all batches in any 6 month period, cap applies to any single batch.

(2) Vapour pressure limit is NSW regulation.

(3) Low volatility fuel was introduced by a memorandum of understanding in 1998 but was not regulated until 2004.

2 More detailed information may be found at **http://www.environment.gov.au/topics/environment-protection/fuel-quality/standards.**

3. National Fuel Standards

Table 5: Key diesel fuel specifications

Property	Standard	Implementation Date
Sulfur	≤500 ppm	31 Dec 2002
	≤50 ppm	1 Jan 2006
	≤10 ppm	1 Jan 2009
Cetane Index	≥46	1 Jan 2002
Density	820-860 kg/m³	1 Jan 2002
	820-850 kg/m³	1 Jan 2006
Distillation T95	370°C	1 Jan 2002
	360°C	1 Jan 2006
Polyaromatic Hydrocarbons	11% by mass	1 Jan 2006

4. In-Service Fleet Performance

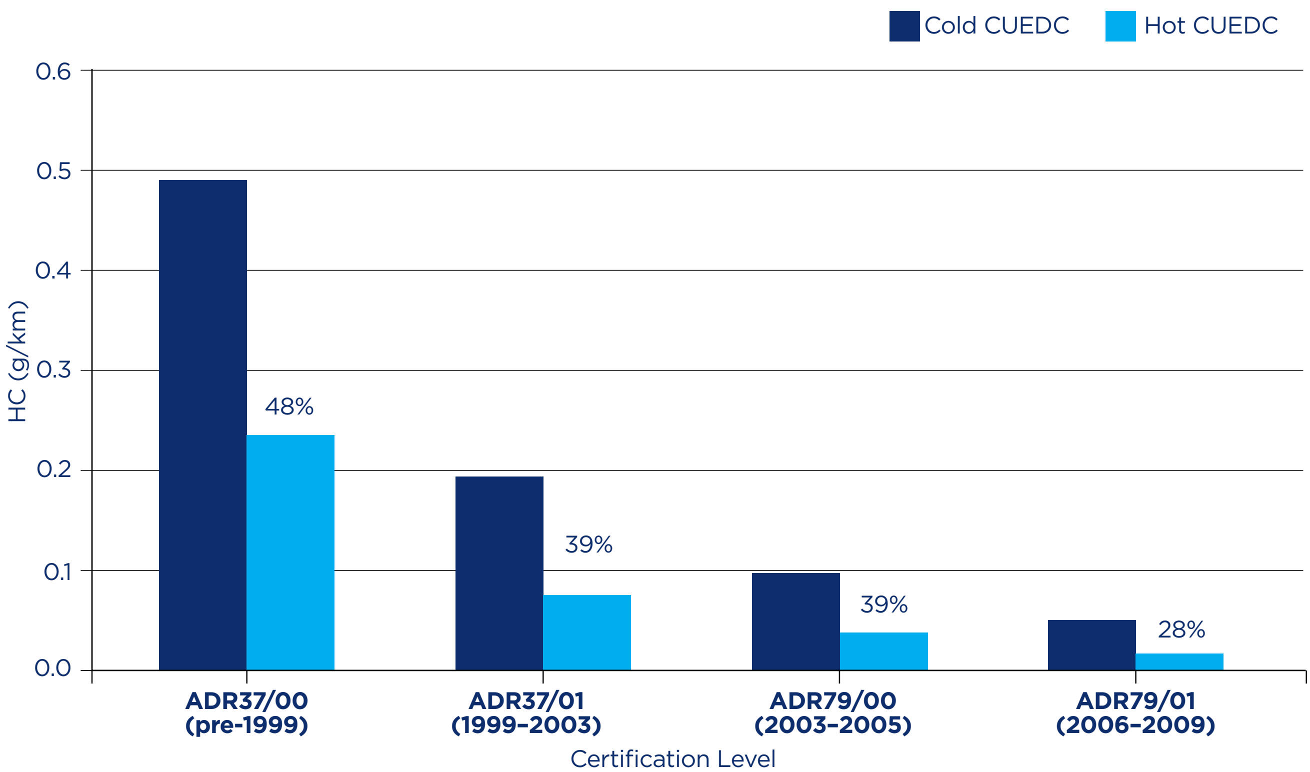
The effectiveness of the tighter emission standards on the in-service petrol passenger vehicle fleet is demonstrated with data from the Commonwealth's Second National In-Service Emission Study (NISE2) (DEWHA, 2009).

The average hydrocarbon (HC) emissions for the four ADR classes tested in the NISE2 project are shown in Figure 1. The data shown is for the 20 km Australian Combined Urban Emission Drive Cycle[3] (CUEDC) for both a start from cold and a start with a fully hot engine. The emission rates are seen to have decreased by an order of magnitude from the ADR37/00 cars of the 1990's to the latest vehicles tested in this project, 2006–07 ADR79/01 (Euro 3) vehicles.

The corresponding NO_x emissions are shown in Figure 2 and are also seen to have decreased by an order of magnitude from ADR 37/00 to ADR79/01.

Although no new test data are available, it would be expected that the newer vehicles under the current ADR79/02 (Euro 4) would have significantly lower emissions than the ADR79/01 vehicles in response to the 50% reduction in the NO_x limit (refer to Table 1).

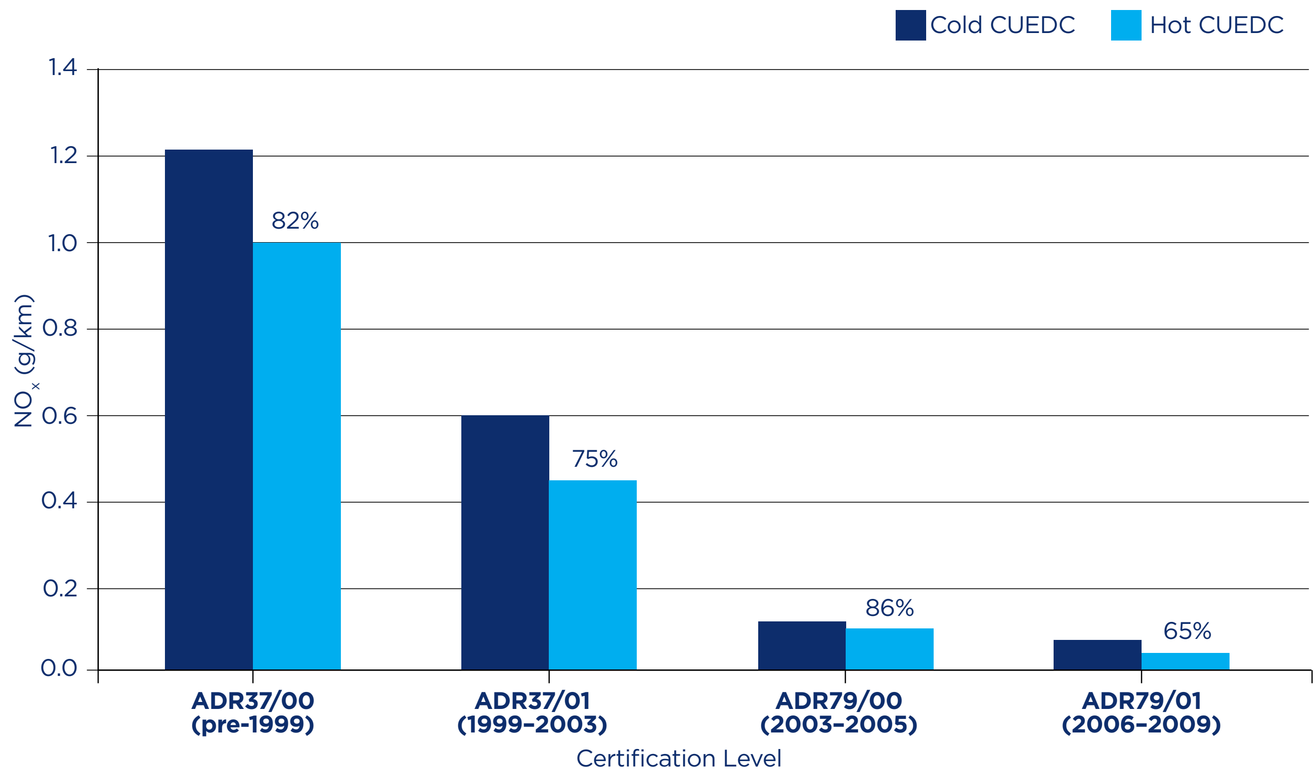
Figure 1: HC emissions for petrol passenger vehicles from NISE2 project (DEWHA, 2009)
(%'s are the hot emissions as % of cold emissions)



3 The Combined Urban Emissions Drive Cycle is a "real-world" vehicle test cycle developed from monitoring of thousands of kilometres of actual vehicle operation across Australian capital cities

4. In-Service Fleet Performance

Figure 2: NO_x emissions for petrol passenger vehicles from NISE2 project (DEWHA, 2009) (%'s are the hot emissions as % of cold emissions)

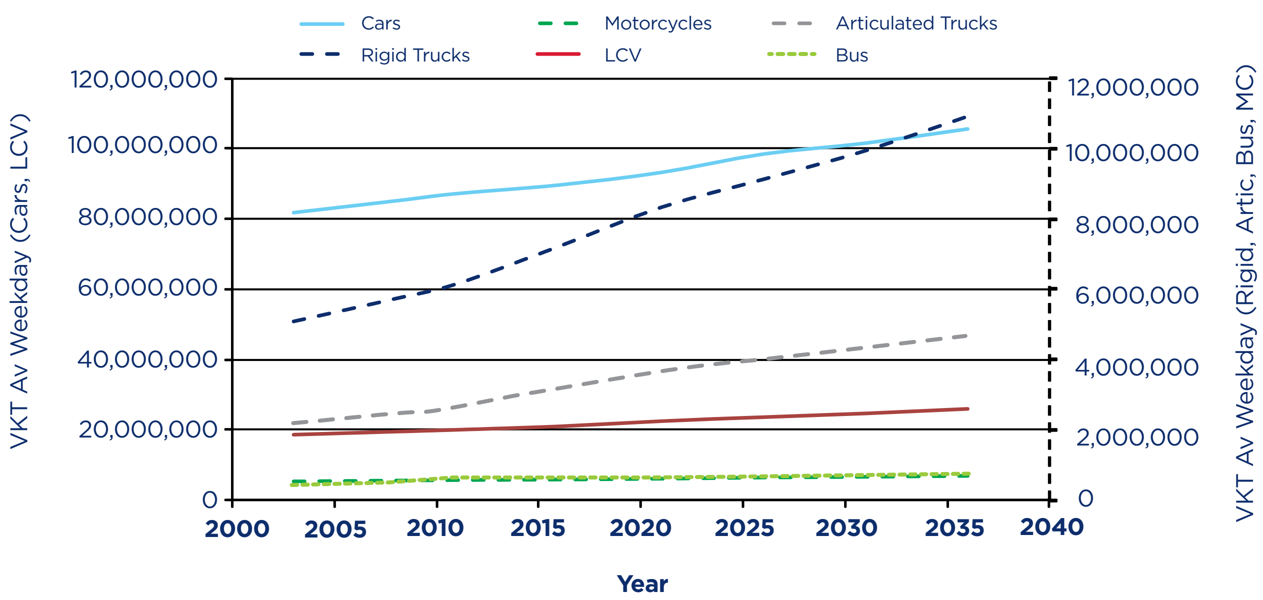


5. Vehicle Kilometres Travelled

Vehicle kilometres travelled (VKT) are estimated by the NSW Department of Transport's Bureau of Transport Statistics (BTS). BTS estimate VKT using sophisticated strategic transport models calibrated with pooled data from the annual NSW Household Travel Survey (HTS) for passenger transport and commercial transport surveys for freight transport (BTS, 2011, TDC, 2010). BTS estimates are generally in agreement with other VKT sources such as the Australian Bureau of Statistics Survey of Motor Vehicle Use (SMVU).

The BTS modelled growths in VKT for passenger vehicles and freight vehicles for the NSW greater metropolitan region (GMR) are shown in Figure 3. The vehicle classes represented by the dashed lines refer to the right hand axis. The total fleet annual VKT growth rate is around 1% per year. Passenger vehicles dominate the VKT and grow at around population growth of 1% per year, while VKT growth rates for both rigid and articulated trucks are in line with economic growth at around 2–3% per year.

Figure 3: Average weekday VKT growth 2003–2036

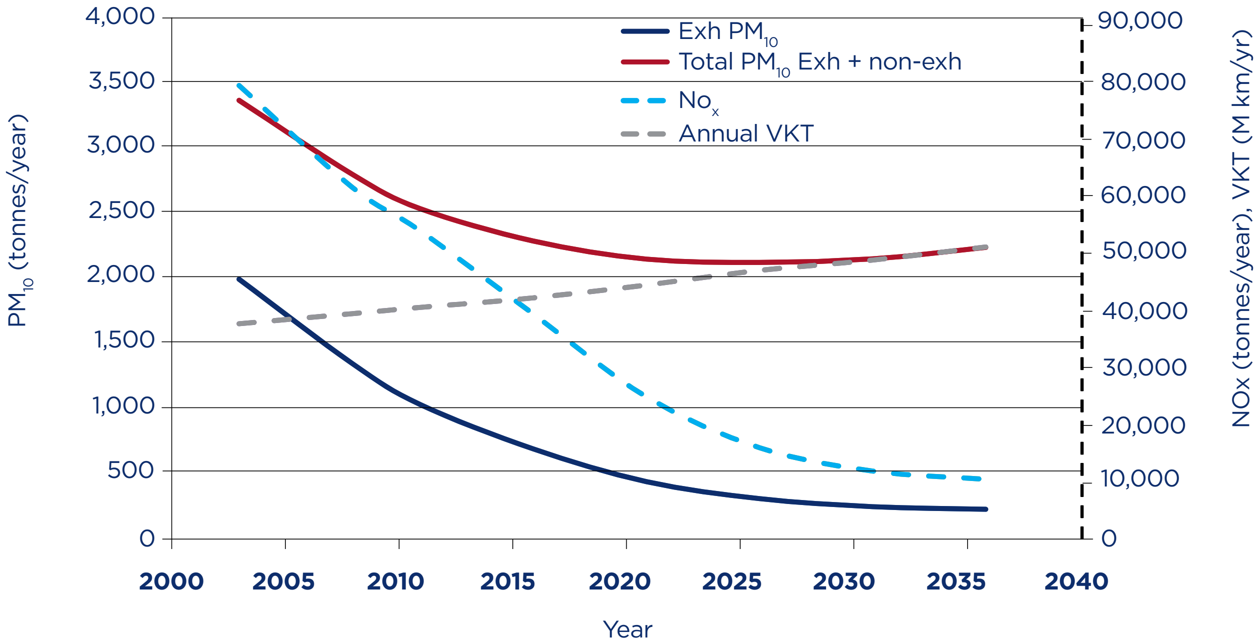


6. Motor Vehicle NSW GMR Air Emission Inventory Projections

The NSW motor vehicle emission inventory model is used to project the entire fleet emissions for the Greater Metropolitan Region (GMR) to future years as shown in Figure 4 (EPA, 2012). VKT growth and congestion are estimated from the BTS data above, and the model includes fleet turnover and the resultant adoption of new technology[4].

The projections given in the figure below assume the adoption of Euro VI heavy diesel emission standards as ADR80/04 from 2017.

Figure 4: Projected NSW GMR motor vehicle emissions (EPA, 2012)



The NO_x and VKT data represented by the dashed lines are plotted against the right hand axis (note VKT is in millions of kilometres per year (M km/yr) ie. 2008 VKT is 38,800 million km per year)

Figure 4 shows two lines for PM_{10}. The blue line is exhaust emissions of PM_{10} and shows strong decreases with the penetration of new technology into the fleet as a direct response to the large reductions in emissions limits in the ADRs. Exhaust PM is mostly less than PM_1 with >99% of particle numbers and >85–90% particle mass < 1.0µm. $PM_{2.5}$ mass comprises more than 95% of the PM_{10} mass shown.

The red line is the total PM_{10} in which the non-exhaust sources of tyre, brake and road wear are added to the exhaust emissions. Non-exhaust particles comprise larger size fractions than exhaust PM, with approximately 47% of mass in the $PM_{2.5}$–PM_{10} range, and only 7% as PM_1. As there is no current abatement technology or legislated standards for the non-exhaust sources of PM, emissions from this source grow as a direct function of VKT. Hence the total PM_{10} reaches a minimum around 2026 and then starts to grow. Note that in the inventory base year of 2008 non-exhaust PM_{10} emissions are approximately equal in magnitude to the exhaust PM_{10} component.

4 Full details of the motor vehicle inventory model are given in the report at **http://www.epa.nsw.gov.au/air/airinventory2008.htm with projection assumptions given in appendix B**

NO_x emissions are also seen to strongly decline into the future as a result of the new low emission vehicles entering the fleet.

Although motor vehicle emissions are projected to decline, health evidence indicates that particulate matter is a non-threshold pollutant and ozone (formed from hydrocarbons and oxides of nitrogen) is also likely to be a non-threshold air pollutant. Hence on-going emission reductions will continue to deliver positive public health benefits (WHO 2013, Bell & Dominici 2008).

The trends in the data shown in Figure 4 as an aggregation across the GMR may not reflect changes in any one location or road corridor which may have significantly different VKT growth rates and traffic mixes. For instance, the rigid truck fleet tends to have a much slower turnover than articulated trucks. The emission contribution by vehicle type is presented in the next section.

6. Motor Vehicle NSW GMR Air Emission Inventory Projections

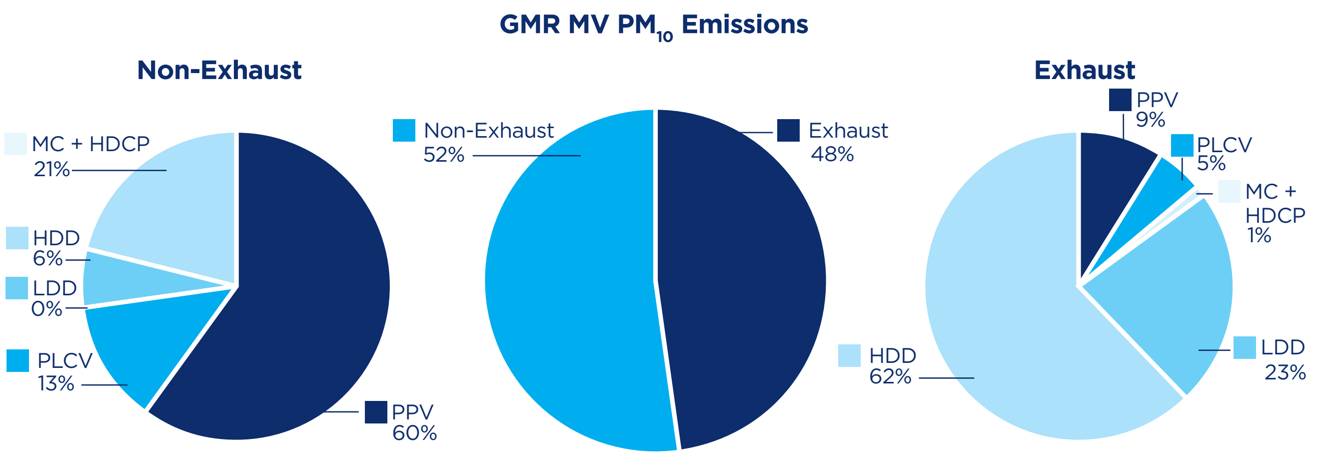
6.1. Emission Contribution by Vehicle Type

The NSW EPA motor vehicle emissions inventory estimates the contribution by vehicle type to the total 2008 NSW greater metropolitan region (GMR) motor vehicle (MV) emissions. This is shown in Figure 5, Figure 6 and Figure 7 for PM_{10}, VOC and NO_x respectively. The vehicle type abbreviations used are given in Table 6.

Table 6 – Vehicle type abbreviations

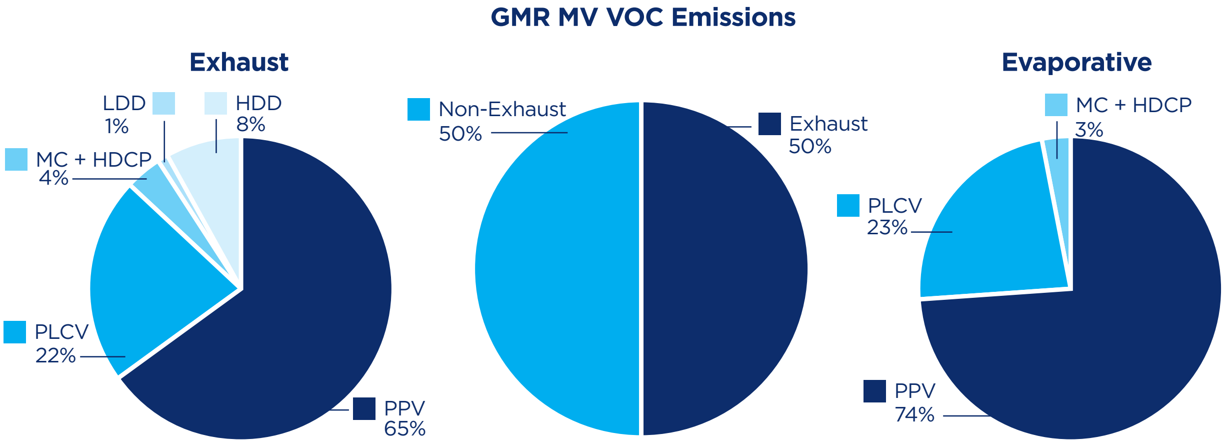
Abbreviation	Vehicle Type
ART	Articulated trucks and heavy truck-trailer combinations
BUS	Heavy diesel public transport buses
DLCV	Diesel light commercial vehicles (utes + vans)
DPV	Diesel passenger vehicles (cars + SUV/4WD)
HDD	Heavy-duty diesels (rigid trucks, articulated trucks, heavy buses)
HDCP	Heavy-duty commercial petrol (>3500 kg)
LDD	Light-duty diesels <3500kg (light commercial vehicles + cars + SUV/4WD)
MC	Motor cycles
MC+HDCP	Motor cycles + heavy-duty commercial petrol
PLCV	Petrol light commercial vehicles (utes + vans)
PPV	Petrol passenger vehicles (cars + SUV/4WD)
RIG	Rigid trucks (>3.5t to ~25tonne)

Figure 5: Contribution by vehicle type to 2008 NSW GMR PM_{10} emissions



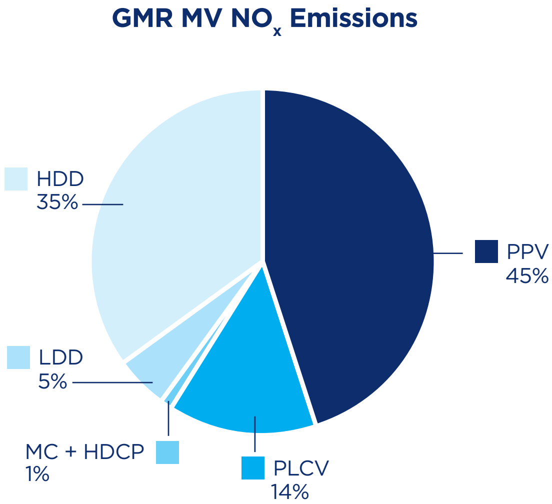
Non-exhaust sources of PM_{10} account for more than half of the total motor vehicle PM_{10}, of which most (60%) is generated by petrol passenger vehicles due to their dominance in VKT. Heavy duty diesel vehicles are disproportionate contributors to PM_{10} exhaust emissions at more than 60% while accounting for only 6% of VKT. Light duty diesel vehicles are also significant contributors at 23% while accounting for 5% of VKT.

Figure 6: Contribution by vehicle type to 2008 NSW GMR VOC emissions



Evaporative fuel emissions and exhaust emissions contribute equally to total motor vehicle VOC emissions. Of the 50% emitted by exhaust, petrol vehicles dominate. Evaporative emissions are only emitted by petrol vehicles.

Figure 7: Contribution by vehicle type to 2008 NSW GMR NOx emissions



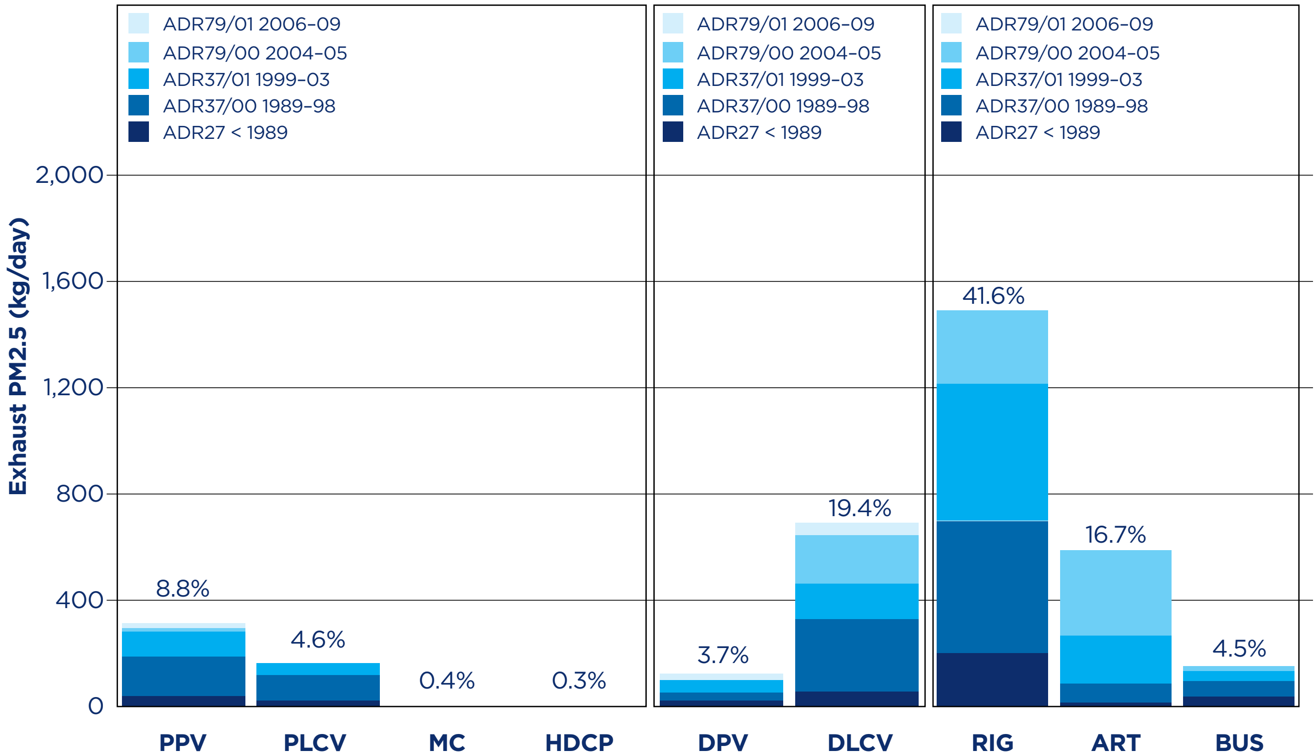
Heavy duty diesels contribute a disproportionate 35% of NO_x emissions, while accounting for only 6% of the entire fleet VKT. Petrol passenger vehicles and petrol light commercial vehicles contribute the majority of the remainder.

The significantly varying rates of emissions of different vehicle types indicates that the composition vehicle fleet on any particular road corridor will be an important factor in the level of emissions in that corridor.

6.2. Emission Contribution by Age

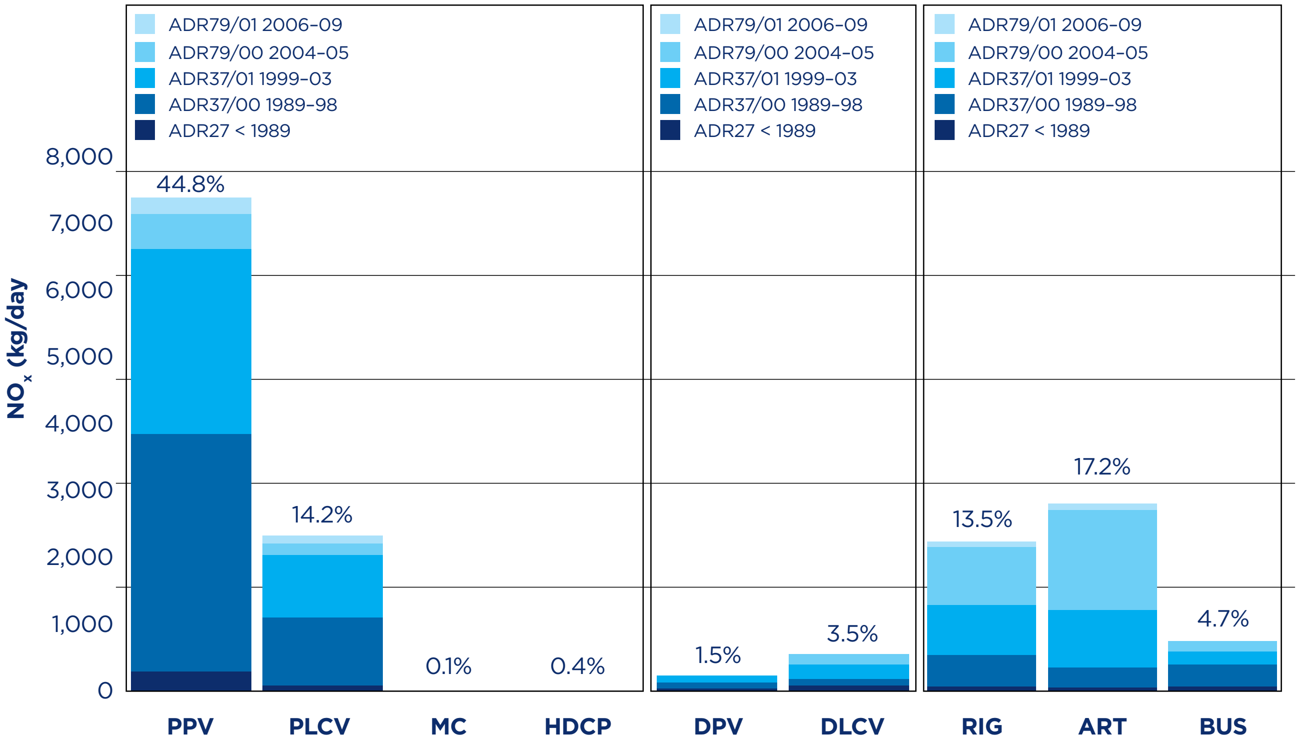
The contribution to the total daily emissions by age class (ADR compliance) and vehicle type are shown in Figure 8 and Figure 9 for exhaust $PM_{2.5}$ and NO_x respectively for the 2008 calendar year. The stacked bars show the emissions by age class with the oldest vehicles at the bottom and the newest at the top. The per cent figures shown are the total contribution of all ages of each vehicle type to total fleet emissions.

Figure 8: $PM_{2.5}$ emission contribution by age class by vehicle type (2008)



As shown in the previous section, exhaust PM is dominated by heavy duty diesels (RIG, ART, BUS) with a significant contribution from diesel light commercial vehicles (DLCV). For the two largest contributors, DLCV and rigid trucks, together comprising over 60% of total exhaust emissions, around 50% of the emissions are produced by vehicles older than 1996 (ADR70/00 and older certification). These pre-1996 vehicles account for only 15% and 18% of the respective vehicle class VKT, and are thus significantly disproportionate contributors to emissions at around 3 times the fleet average emission rate (per kilometre). For articulated trucks, the pre-1996 vehicles contribute 17% of the $PM_{2.5}$ emissions and account for 9% of the VKT, and hence are emitting at around twice the fleet average rate.

Figure 9: NO_x emission contribution by age class by vehicle type (2008)



For NO_x the dominant contributors are petrol passenger vehicles and petrol light commercial vehicles. The pre-1999 petrol vehicles (pre-ADR37/01) contribute approximately half of their respective vehicle type emissions, but only account for around 30% of the VKT.

The high emission rates of older vehicles in the fleet indicate that the fleet age profile, in addition to the vehicle type composition, are an important factor in estimating the level of emissions from any specific road corridor.

7. References

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Appendix A: Australian ADR Emission Limits

Figure A1: Petrol light duty carbon monoxide emission limits

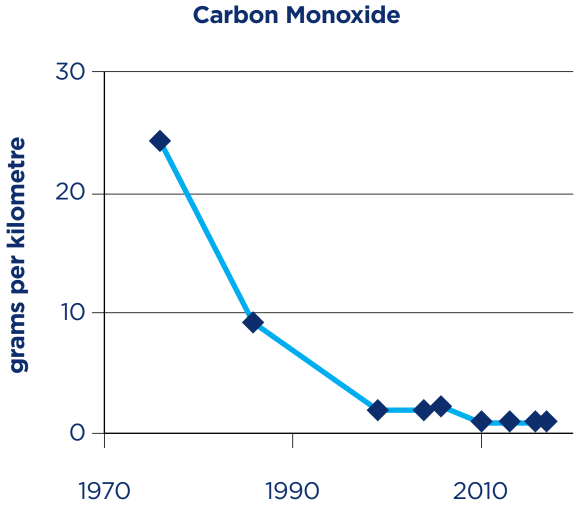


Figure A2: Petrol light duty hydrocarbon emission limits

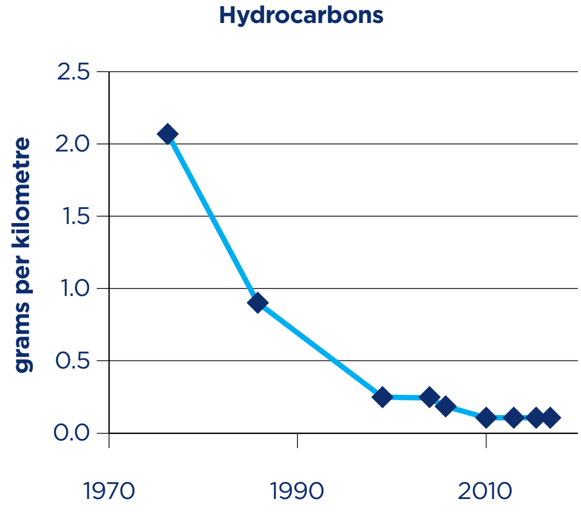


Figure A3: Petrol light duty oxides of nitrogen emission limits

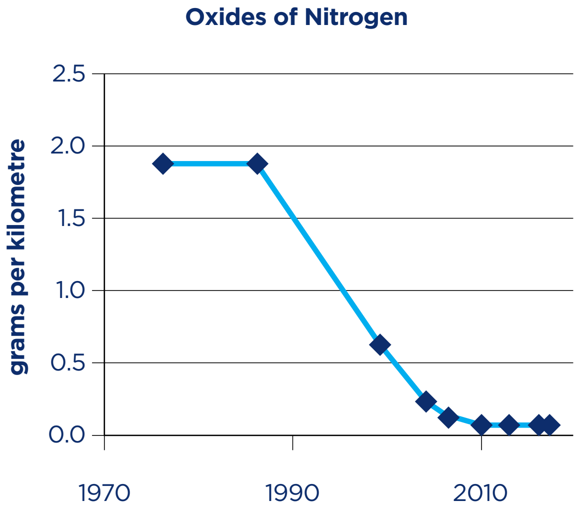
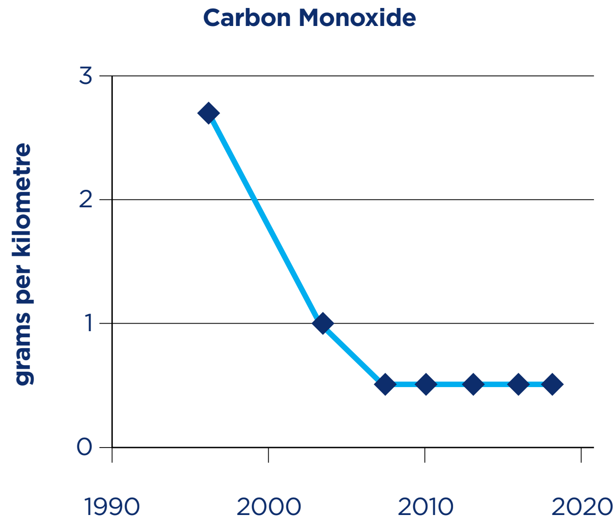


Figure A4: Diesel light duty carbon monoxide emission limits



Appendix A: Australian ADR Emission Limits

Figure A5: Diesel light duty combined hydrocarbon and oxides of nitrogen emission limits

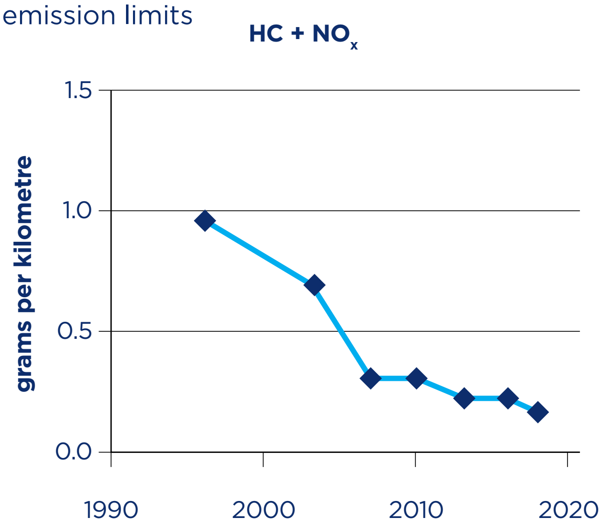


Figure A6: Diesel light duty particulate matter emission limits

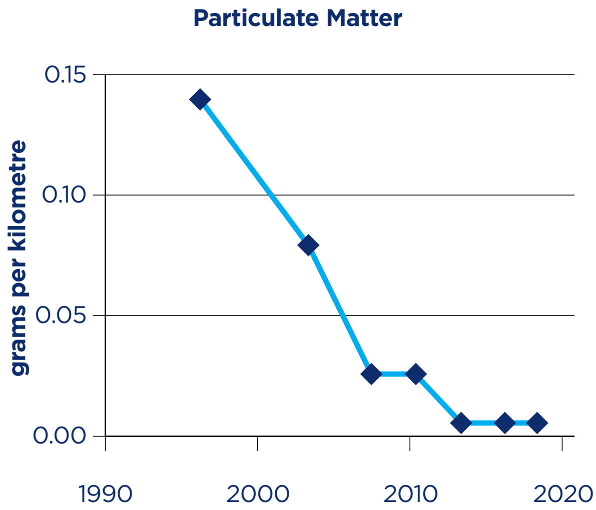


Figure A7: Diesel heavy duty carbon monoxide emission limits

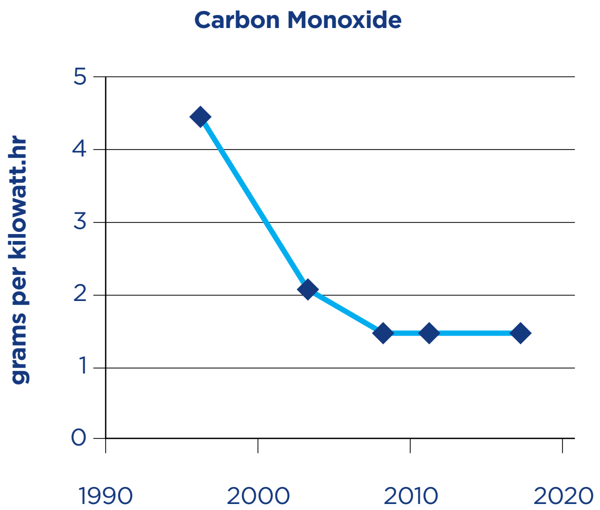


Figure A8: Diesel heavy duty hydrocarbon emission limits

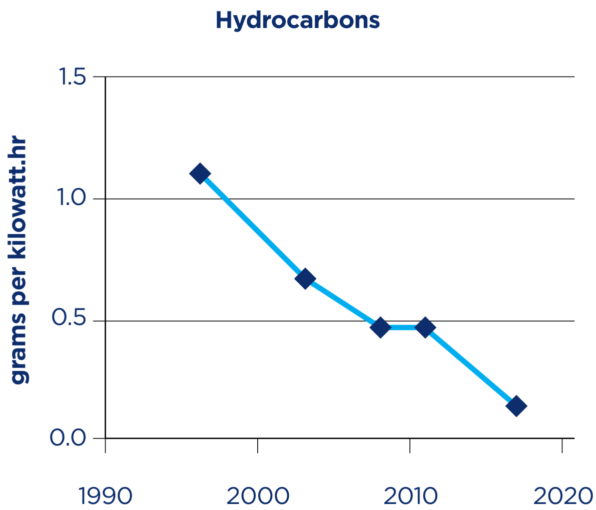


Figure A9 – Diesel heavy duty oxides of nitrogen emission limits

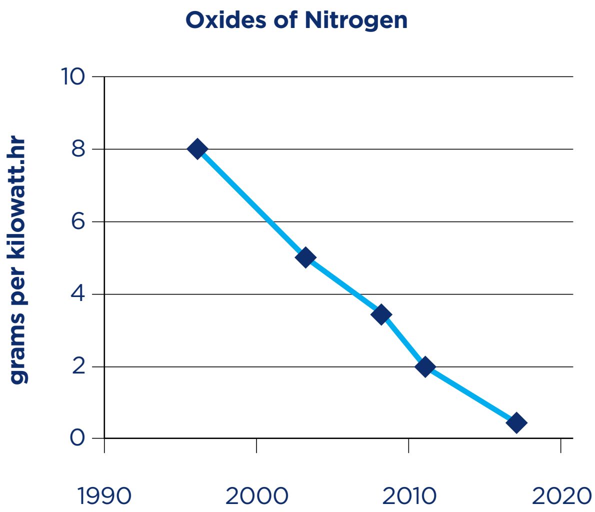


Figure A10 – Diesel heavy duty particulate matter emission limits