Cleaner Non-road Diesel Engine Project – Identification and Recommendation of Measures to Support the Uptake of Cleaner Non-road Diesel Engines in Australia

Final Report

Prepared for:
NSW Department of Environment, Climate Change and Water

On behalf of:
NSW Department of Environment, Climate Change and Water
and
Australian Government Department of the Environment, Water, Heritage and the Arts

Prepared by:
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Key Findings

Non-road diesel engines and equipment are used in a wide variety of applications including construction, industrial and airport services and can be high pollution emitters. Almost all large non-road engines are diesel powered and these engines, on an individual basis, emit considerably more particulate matter than petrol engines and a disproportionate amount of oxides of nitrogen (NO_x).

Equipment in which non-road engines are used is extremely diverse, with identical engine types often used in widely varying equipment applications. Diesel engine configurations on the market differ significantly in terms of engine size and power rating. As a result of these variations in the types and applications of non-road diesel engines, the emission characteristics of these engines vary widely.

Diesel engines are not manufactured locally but are imported into Australia, either as stand-alone units or as a component of equipment. About 74,000 non-road diesel engines/equipment were imported into Australia during 2008.

The non-road diesel sector (excluding rail and marine transport) consumes a similar volume of automotive diesel oil as the on-road diesel vehicle sector.

Nationally, non-road diesel engines are estimated to emit around 13,500 tonnes of particles (as PM10) per annum. This is of a similar magnitude to emissions from the on-road vehicles sector. NO_x emissions from non-road diesel engines are estimated to be around 92,700 tonnes per annum and represent over a quarter of the total NO_x emissions from on-road vehicles in urban airsheds.

In Australia there are no regulations or standards in place that limit emissions from non-road diesel engines. Regulated emission limits for non-road engines have been in force in the US and EU since the mid-1990s. China, India, Japan and Canada also have regulated emission limits for non-road engines.

Reducing emissions from this sector would contribute to reducing particle and ozone pollution, and associated health risks, in cities and regional Australia.

The emission compliance of new non-road diesel engines sold in Australia was assessed against United States (US) and European Union (EU) standards and found to be behind emissions limits applying to comparable non-road engines sold in those jurisdictions.

About 22% of non-road diesel engines sold in 2008 were estimated to be non-compliant with US or EU standards or only compliant with 1996-2000 US Tier 1 (EU Stage I) emission standards. The compliance status of a further 9% was unknown, and potentially non-compliant.

A significant proportion (47%) of engines was found likely to be compliant with older 2000-2006 US Tier 2 (EU Stage II) standards. Only 5% of engines were reported by industry as meeting 2008 US Tier 4i (2008) standards.

Approximately 36% of all diesel engines sold in Australia were reported by industry as being certified to an international emission standard.

Particle (PM_{10}) emission reductions achievable through compliance with latest US standards are estimated to be between 5,600 and 10,200 tonnes per annum to 2020, increasing to 7,300 to 14,100 tonnes per annum by 2030. It should be noted that:

- Emission controls on larger (above 56 kW) engines account for 88% of the overall potential PM emission reductions from the non-road diesel sector.

- Small engines (below 19 kW) are estimated to account for about 2% of the overall PM emission reductions, with very small engines (below 8 kW) responsible for 0.1% of the overall reductions. A significant proportion of agricultural equipment falls into these categories.

The establishment of US emission limits in Australia are estimated to result in annual NO_x emission reductions of between 44,100 and 65,600 tonnes per annum by 2020, and in the range of 57,000 to 92,300 tonnes per annum by 2030.

Annual environmental (health) benefits associated with PM_{10} and NO_x emission reductions are estimated to be in the range $2.5 to $4.7 billion (2008 AUD) by 2030.

The establishment of national non-road diesel regulations based on existing overeseas standards is the preferred approach to effectively address emissions from this sector. This would require a regulatory impact assessment to be conducted, which includes a detailed cost benefit analysis to assess the merits of regulation and thorough stakeholder consultation on potential options to reduce emissions.

Given that the specific locations of non-road engine/equipment applications are not known it is important that the cost benefit analysis considers urban and rural impacts. Options that could be assessed in the cost benefit analysis include an exclusion of small engines i.e. 0 to 8 kW engines and consideration of excluding engines/equipment in the 8 to 19 kW, given their minimal impact on PM emissions.

Executive Summary

National air quality standards for particles (PM_{10}) and ozone are regularly exceeded in Australian cities, with significant implications in terms of adverse health effects and environmental impacts.

The contribution of non-road engines to total anthropogenic NO_x (a precursor pollutant necessary for the formation of photochemical smog, notably ozone) and particle emissions has been concluded by previous national and state studies to be worthy of further consideration[(2)(3)]. The 2005 national study concluded that the introduction of management programs for these emissions would appear to be justified.

Regulations for non-road (off-road) equipment have been introduced by various countries over the past 15 years, including the US, Europe, Canada, Japan, India and China. Significant emission reductions have been achieved through such measures in the US and Europe over the past decade.

Australia does not currently have regulations in place that limit emissions from non-road diesel engines and equipment. However, Australia has benefited somewhat through the importation of engines compliant with US, EU and other emission standards, which have contributed to reduced emissions from this sector.

Study Objective

ENVIRON Australia (Pty) Ltd was commissioned by the NSW Department of Environment, Climate Change and Water (NSW DECCW) and the Australian Government Department of the Environment, Water, Heritage and the Arts (DEWHA) to identify and recommend measures to support the supply and purchase of cleaner non-road diesel engines so as to reduce emissions from these engines in Australia. Key components of the study include:

- Characterisation of the Australian non-road diesel product sector, considering stakeholder readiness for cleaner products, and niche markets amenable to targeted voluntary schemes.
- Assessment of the impact of in-service and new non-road diesel engine/equipment emissions across Australia.
- Assessment of the likely effectiveness and suitability of implementing international measures to reduce emissions from new non-road engines/equipment in Australia.
- Quantification of emission reductions achievable through compliance with international emission standards.
- Recommendations for feasible measures to reduce emissions from the non-road diesel sector.

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2 PAE (2005). Management Options for Non-road Engine Emissions in Urban Areas, Report compiled by Pacific Air and Environment on behalf of the Department of the Environment and Heritage, November 2005.
3 NSW DECCW (2007). Air Emissions Inventory for the Greater Metropolitan Region in New South Wales, New South Wales, Department of Environment, Climate Change and Water, Sydney.

The focus of the study is on the multiple non-road diesel engines market segments such as airport service equipment (e.g. terminal tractors, ground power units etc.); industrial equipment (e.g. aerial lifts, forklifts, sweepers, scrubbers etc.); construction equipment (e.g. excavators, cranes, graders, etc.); mining and agricultural equipment. International and interstate commercial marine and diesel locomotive sectors are not included in the scope of the study.

Non-road Diesel Engine Fuel Use and Applications

As indicated in the key findings the non-road diesel sector (excluding rail and marine transport) consumes a similar volume of automotive diesel oil (ADO) as the on-road diesel vehicle sector. In 2007-8, total ADO consumption is reported by ABARE to be 17.8 gigalitres (GL), with about 45% of this being consumed by the road transport sector, and a further 8% used for rail, pipeline and marine transport[(4)].

About 8.1 GL of ADO (45% of total consumption) is used in other non-road and non-water transport applications within the agriculture, forestry, fishing, manufacturing, construction, mining, commercial and electricity sectors. Mining and Construction was reported to consume about 47% of this 'non-road ADO'; Agriculture, Forestry and Fishing account for a further 25%, with the remainder being consumed by the Manufacturing (12%), Electricity (8%), Commercial/Services (7%) and Residential (<1%) sectors.

Non-road diesel engines and equipment are used in a wide variety of applications including construction, farming, industrial, and airport services. As a result of technological developments and the wide range of applications, diesel engine configurations on the market vary significantly in terms of combustion chamber design, fuel-injection system, engine size and power rating. The diversity of applications is also reflected in the range of fuel characteristics and engine operating conditions for in-service engines. All of these factors impact on emissions from non-road diesel engines. This has implications for targeting specific engines/applications for emissions management.

Australian equipment manufacturers import rather than manufacture the diesel engines that are incorporated into their equipment. This means that for emission management measures to be effective, they need to target both engine and equipment manufacturers.

Air Quality Impacts of Non-road Diesel Engines/Equipment

PAE (2005) estimated the number of in-service non-road diesel engines to be in the order of 550,000, based primarily on 2003 data[(5)]. Based on likely sales trends and rates of engine scrappage, PAE estimated the number of in-service diesel non-road engines to be in excess of 620,000 by 2008.

Emission inventories for in-service non-road diesel applications in Australia were developed using representative US-EPA NON-ROAD 2008 emission factors. Australian engine

4 ABARE (2009). Energy in Australia 2009, Australian Government Department of Resources, Energy and Tourism.
5 PAE (2005). Management Options for Non-road Engine Emissions in Urban Areas, Report compiled by Pacific Air and Environment on behalf of the Department of the Environment and Heritage, November 2005.

attributes (e.g. load factors; annual operating hours; emission performance), when available, were used to develop the inventories.

Total emissions of particulate matter (PM_{10}) and oxides of nitrogen (NO_x) were estimated to be 13.5 kilo-tonnes per annum (ktpa) and 92.7 ktpa respectively.

The most significant non-road diesel engine/equipment applications, in terms of both PM_{10} and NO_x emissions, were found to be Construction and Mining Equipment followed by Agricultural and Forestry Equipment. Construction and Mining Equipment accounted for 61% of PM_{10} emissions and 56% of NO_x emissions for the in-service non-road diesel fleet. Agricultural and Forestry applications were responsible for 30% of PM_{10} emissions and 33% of NO_x emissions.

Nationally, PM_{10} emissions from non-road diesel engines are estimated to be of a similar magnitude as emissions from the on-road vehicles sector. NO_x emissions from in-service non-road diesel engines are estimated to represent about 27% of the total NO_x emissions of on-road vehicles in urban airsheds.

Based on 'non-road' ADO consumption rates, the highest non-road diesel engine emissions occur within Western Australia (30%), Queensland (28%) and NSW (20%), with emissions for other states/territories estimated to be in the range of 3% to 9%.

Review of International Measures to Manage Non-road Diesel Emissions

A review of international measures to manage emissions from **new** non-road diesel engines and equipment identified a number of key measures:

- Government regulation of non-road diesel engines and equipment, including emission limits based on engine type and power output and associated compliance testing procedures.
- Co-regulation, with voluntary emission standards, adopted through agreement with relevant manufacturers and importers.
- Voluntary emission standards and recognition programs.
- Fuel quality standards, specifically sulfur content requirements.
- Emission limit requirements for new non-road diesel equipment stipulated as part of government contracts.

Market segments and applications targeted abroad by non-road diesel engine/equipment emission management measures most typically include the following diesel-powered engines/equipment:

- Construction and mining equipment and non-road vehicles.
- General industrial equipment and non-road vehicles, including aviation service equipment.

- Light commercial equipment, including pumps and compressors.
- Power generation units, including those over 900 kW (in the case of the US).
- Agricultural equipment and vehicles (including tractors and other self-propelled machinery, pumps and generators).
- Logging equipment.
- Lawn and garden equipment.
- Marine engines – specifically small 37 kW engines in the case of the US, and inland water vessels in the case of the European Union (EU).

Although distinctions are made between market segments in emissions inventories, regulations and regulatory impact assessments for non-road diesel engines in the US, Europe and elsewhere tend to focus on *engine rating classes*. The main reasons for this include: efficiency of regulation, and the fact that the same diesel engines are used in equipment and vehicles implemented within several market segments.

The engine power rating ranges which are covered by non-road diesel regulations include non-road diesel engines (across the above mentioned market segments) within the following power bands:

Less than 8 kW	US; Canada; China; India
8 – 19 kW	US; Canada; China; India (being considered by EU)
19 – 560 kW (various bands)	US; Canada; China; India; EU; Japan
>560 kW	US; Canada; (being considered by EU)

Emission limit requirements for new non-road diesel equipment stipulated as part of government contracts overseas tend to focus on heavy industrial (construction, mining) equipment types with an emphasis on greater than 37 kW equipment.

To reduce in-service emissions, international experience demonstrates only diesel retrofit programs targetting heavy industrial (construction) equipment being adopted. Such programs may be either voluntary (with or without incentives) or mandatory.

International Emission Standards for Non-road Diesel Engines/Equipment

The US and EU emission standards are the most widely referenced and applied international emission standards for non-road diesel engines. Since their inception, these standards have become more stringent, achieved more extensive coverage, and are moving towards harmonisation.

The most stringent standards (equivalent to US Tier 4) require significant reduction in PM and NO_x emissions (~90% reductions). Such emission standards are only achievable through the use of emission control technologies, including advanced exhaust technologies. The incorporation of sulfur-sensitive control technologies such as catalytic particulate filters and NO_x adsorbers in engines has also necessitated reductions of sulfur content in diesel fuels.

Key differences between the US and EU emission standards include the engine classes and applications covered, notably:

- US emission standards have wider coverage including small engines (less than 8 kW) and large engines (greater than 560 kW) including generation sets of greater than 900 kW. EU emissions standards are generally only applicable to mobile engines greater than 18 kW and less than 560 kW(6).
- Although both US and EU non-road diesel emission standards include certain marine engines, the manner in which these engines are defined differs significantly. The US primarily bases its definition on engine size, with marine engines smaller than 37 kW being subject to non-road diesel emission standards. The EU definition for inland waterway vessels is complex, with a number of exclusions.

Non-road diesel engine PM emissions standards published by the US, EC, Japan, China and India (excluding standards applicable post 2010) were compared. Whereas the non-road diesel emissions standards published by Japan are more in line with the Stage IIIA and US Tier 4i PM emission standards, emission standards applied in China and India are lagging and more indicative of EU Stage I/II and US Tier 1/2 emission standards.

Australian Non-road Diesel Product Sector

Characterisation of the non-road diesel product sector in Australia was based on a review of previous studies, collation and analysis of existing data sets, industry consultation and a survey of engine/equipment suppliers. Reference was made to import and export statistics available from the Australian Bureau of Statistics, sales data from the industry associations including the Construction, Mining Equipment Industry Group (CMEIG), and the Australian Diesel Engine Distributors Association (ADEDA) and the Tractor and Machinery Association of Australia (TMA). Emission performance information for specific brands and models were obtained through the survey of identified major engine and equipment suppliers.

Industry Structure

Diesel engines are not manufactured locally but rather imported into Australia, either as loose diesel engines or already incorporated into equipment.

6 Outcomes from the EU regulatory review process include recommendations to extend regulations to include greater than 560 kW and 8 to 19 kW engines/equipment, but to continue to exclude 0-8 kW engines from regulation. Information drawn from Van Zeebroeck B, Vanhove F and Franckx L (2009). Impact Assessment Study – Reviewing Directive 97/68/EC – Emissions from non-road mobile machinery, Final Report, European Commission, 30 January 2009..

Loose diesel engines refer to engines sold for use in new equipment or as replacement engines for in-service equipment. Loose engines are the single largest non-road engine sales category.

Engine and equipment sales are typically dominated by a small number of leading brands with the remaining small proportion of the market being shared by a wide range of alternative brands.

The leading Australian industry associations for non-road diesel engines and equipment are the recently constituted Australian Diesel Engine Distributors Association (ADEDA); the Construction and Mining Equipment Industry Group (CMEIG); and the Tractor and Machinery Association of Australia (TMA).

Engine/Equipment Imports

About 73,900 non-road diesel engines/equipment were imported into Australia during 2008, comprising: loose diesel engines and power generation sets (gen sets) (40%), agricultural equipment (26%), and heavy industrial, construction and mining equipment (24%). The remaining 10% of imports included other industrial equipment (airport ground service equipment, cranes, forklifts), light commercial equipment (compressors, welders, pressure washers) and lawn ride on and tractor mowers.

Used diesel engines were estimated to account for less than 3% of total imports, and include used vehicle propulsion engines (70%), heavy industrial (construction, mining) equipment (20%) and agricultural tractors (6%)[(7)]. However, in the absence of emission management measures and given increasing regulation abroad, there may be a growth in new and used engine/equipment imports with poorer emission performance.

Japan, the US and China are the largest sources of non-road diesel imports, together accounting for 67% of total imports across these equipment categories. Germany, Italy, the UK, Korea, Sweden, France and India represent more minor sources of total imports.

National Engine/Equipment Sales

Non-road diesel engine/equipment sales estimates for 2008 are given in **Table 1**, with the basis for the sales estimates provided.

Non-road diesel engine/equipment sales were estimated to be 56,233 for 2008 (i.e. 76% of imports). This difference between sales numbers and imports is mainly due to the lower sales figures for agricultural tractors (tractor sales being ~60% of reported tractor imports) and loose diesel engines and gen sets (sales being 76% of loose engines and gen sets imports). Engine and gen set exports are expected to account for the latter[(8)]. The reason for the difference in imports and local sales figures for agricultural tractors is unclear. Given industry confidence that sales figures are reasonably complete, it is possible that import statistics do not accurately reflect the influx of actual working agricultural tractors.

7 Used vehicle propulsion engines include on- and off-road engines. Engines initially manufactured abroad for the on-road market may however be applied within various non-road applications.
8 About 13,400 non-road diesel engines were reported to be exported from Australia during 2008. Given that no engines are locally manufactured, these engines represent units previously imported.

The estimated annual sales of non-road diesel engine/equipment in 2008 (56,233 units) represents about 9% of the extrapolated in-service non-road diesel population for 2008 (~620,000 units). This percentage is comparable to that documented for the United States (10%).

Table 1: Estimated Non-road Diesel Engine/Equipment Sales for 2008

Market Segment	Engine/Equipment Description	Number of Units Estimated to be Sold (2008)	Basis for Estimate
Industrial (Industrial, Commercial, Construction, Mining)	Engines for Construction & Mining Equipment	3,422	(a)
	Engines for Industrial Pumps	2,903	(a)
	Engines for 'Other' Industry Equipment(f)	3,726	(a)(h)
	Engines for Miscellaneous Industry Applications	1,611	(a)
	Tractors (expected to include airport equipment)	562	(b)
	Forklifts	609	(b)
	Cranes and lifting equipment	2,850	(b)(h)
	Heavy Construction, Mining, Industrial and Commercial equipment (e.g. loaders, rollers, dumpers)	12,441	(c)(h)
Agricultural	Engines for Pumps & Irrigation	3,964	(a)
	Engines for agricultural vehicles	20	(a)
	Engines for 'Other' agricultural applications(g)	60	(a)
	Agricultural tractors	12,101	(d)(h)
	Combine harvester-threshers	538	(d)
	Windrowers	66	(e)
	Self Propelled Sprayers	333	(d)
	Balers	0	(j)
Power Generation (various markets)	Power Gen Drives - Prime Power	1,320	(a)
	Power Gen Drives - Standby Power	1,326	(a)
	Power Gen Drives - Marine Auxiliary	118	(a)
	Power Gen Sets - Prime Power	1,382	(a)
	Power Gen Sets - Standby Power	1,190	(a)
	Power Gen Sets - Marine Auxiliary	202	(a)
	Power Gen Sets - Miscellaneous	869	(a)
Lawn and Garden	Ride on or tractor lawn mowers	1,900	(b)
Light Commercial	Welders, air compressors, pressure washers	1,000	(b)
Marine (<37 kW)	Propulsion engines for pleasure boats (<37 kW)	440	(a)
	Propulsion engines for work boats (<37 kW)	28	(a)
	Propulsion engines for fishing boats (<37 kW)	6	(a)
	Marine propulsion engines (not specified) (<37 kW)	17	(a)
Forestry	Log Skidders	30	(c)
Potential non-road applications	*Vehicle Propulsion (used)*	*1,199*	*(h)*
TOTAL		56,233	

(a) ERG International 'Loose Diesel Engine and Gen Set Sales Data' for 2008, supplemented by data from several industries not reporting to ERG. Reference should be made to Appendix C for a definition of the application categories.

(b) Assumed equivalent to estimated imports (Table 19).

(c) ERG International 'Construction and Mining Machinery Sales Data Set' for 2008. Specific equipment types include: Hydraulic Excavators, Mini Excavators, Wheel Loaders, Dozers, Crawler Loaders, Motor Graders, Scrapers, Dump Trucks – Rigid and Articulated, Backhoe Loaders, Skid Steer Loaders and Road Rollers.

(d) Sales data obtained for 2008 from the TMA.

(e) Based on 2004 sales data, taking into account PAE (2005) estimate that 99.2% of in-service combines are diesel.

(f) Includes engines for waste removal equipment, road sweeping and cleaning equipment, hydraulic power packs and welding sets.

(g) Includes engines for hay making machinery, oil tresses, lawn and garden outdoor power equipment.

(h) Includes used engine imports. Data received from AQIS, 2009.

(j) No self-propelled balers are used in Australia according to the TMA (October 2009).

Market Chararacterisation of Engine/Equipment Sales

Broad industrial applications (including industrial, commercial, construction and mining applications) are estimated to account for 50% of non-road diesel engine/equipment sales. Agricultural applications represent the second largest use (30%), followed by Power Generation across markets (11%). Together these three categories account for over 90% of non-road diesel engines/equipment sales. More minor applications include Lawn and Garden (3.4%), Light Commercial (1.8%), Marine Propulsion (0.9%) and Forestry (0.1%).

Market Share by Engine Rating

Non-road diesel engines differ from on-road engines in that they range widely in engine size and power ratings.

Small engines (less than 19 kW) make up almost 30% of the total market while only 3% of engines sold fall within the greater than 560 kW range. These engine categories are subject to non-road diesel emission regulation in the the United States but currently are excluded from such regulations by the EU. The addition of such engine categories is however under review by the EU.

Agricultural pumps and irrigation applications are dominated by small engines (76% less than 8 kW; 80% less than 19 kW). The average power rating of agricultural tractors sold is of the order of 60 kW, with about 20% of tractors being smaller than 19 kW. About 86% of heavy industrial (construction, mining) equipment falls in the 19 kW to 560 kW range, with only 6% less than 19 kW.

Trends in Non-road Diesel Engine Sales

The extent of non-road diesel engine/equipment sales has grown over the last decade, with a post 2005 reduction in loose diesel engine sales being off-set by the increase in agricultural tractor sales.

Non-road diesel engine/equipment sales data by state were available for 76% of total numbers sold. Sales data obtained from individual suppliers were not available on a state-by-state basis. The bulk of the sales are within Queensland (30%), NSW (25%), Victoria (21%) and Western Australia (14%).

Emission Performance Status

The emission compliance for non-road diesel engines was determined largely by direct industry surveys, together with consultations with industry and industry associations, review of previous studies and collation of publicly available product information. Overall, the emission compliance status (with international emissions limits such as those issued by the US and EU for non-road diesel engines of about 90% of inventoried non-road diesel engine/equipment sold into the Australian market during 2008 was based on industry data, or estimated. In the case of engines given as complying with a specific standard, it was determined whether certification of compliance had been achieved [9].

The compliance status of about 10% of engines/equipment could not be established, comprising primarily of power generation drives and sets and agricultural equipment (other than agricultural tractors). Information on the compliance status was not in the public domain, nor made available by engine/equipment suppliers during the course of the study.

The emissions performance of non-road diesel engines/equipment inventoried as being sold into Australia during 2008, expressed in terms of *compliance* with international standards, is illustrated in **Figure 1**.

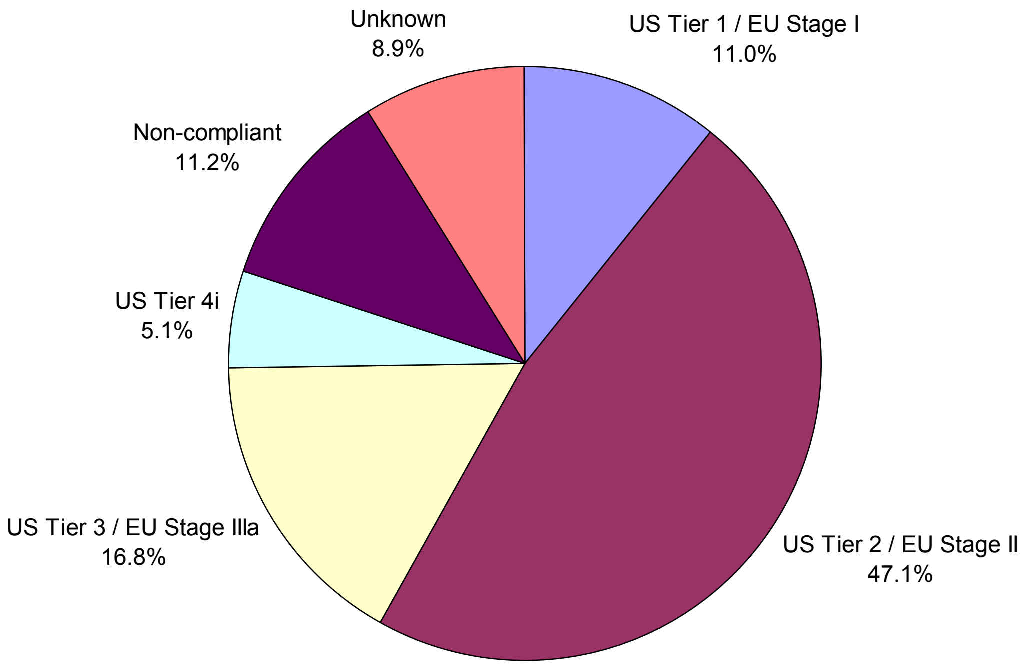

Figure 1: Emissions performance status of non-road diesel engines/equipment sold into Australia during 2008 (in terms of *compliance* with international standards). Implementation dates for US emission standards are as follows: Tier 1 (1996-2000), Tier 2 (2001-2005), Tier 3 (2006-2008), Tier 4i (2008) and Tier 4 final (2011-2015).

Small engines (less than 19 kW) were mainly non-compliant or Tier 2 compliant. The percentage of Tier 3 and Tier 4 interim compliant engines increased with higher power ratings.

Approximately 36% of all diesel engines sold in Australia were reported by industry as being *certified* to an international emission standard. Engines/equipment compliant with more stringent standards (i.e. units able to meet emission standards) were more likely to be

9 Certification comprises the engine/equipment having the necessary documentation, certified by the competent authority, that the engine/equipment supplied meets the required specifications.

certified (87% of US Tier 4 interim compliant engines were given as being certified, compared to 55% of US Tier 3 compliant engines, 46% of US Tier 2 compliant engines and 9% of US Tier 1 compliant engines).

Sector-specific observations in regard to the emission performance of non-road diesel engines are provided in the main body of the report for all sectors inventoried. Observations in respect of the most significant sectors are as follows:

- *Industrial (Construction, Mining) Equipment -* About 23% of industry equipment/engines were non-compliant or Tier 1 compliant. A significant proportion of industrial engines/equipment are either Tier 2 (36%) or Tier 3 (26%) compliant. About 9% of industrial engines/equipment were reported by industry to comply with Tier 4 standards.

- *Industrial Pumps* - A significant portion of industrial pumps are reported to be non-compliant (55%), with the remainder generally being Tier 2 or higher compliant.

- *Power Generation Sets*[(10)] - 11% of power gen sets were reported to be non-compliant with 36% Tier 2 compliant and 15% Tier 3 compliant. Only 1% of gen sets were reported to be Tier 4 compliant

- *Power Generation Drives*[(11)] - Classifiable power generation drives are mainly Tier 2 / Stage II compliant (67%), with the remainder being mainly Tier 4i / Stage IIIa compliant (9%). Only 1.4% of power generation drives were identified as being non-compliant.

- *Agricultural Tractors -* Based on qualitative information obtained from the TMA and accounting for used agricultural tractor sales, 1% of tractors were concluded to be non-compliant, 20% Tier 1 compliant, almost 70% Tier 2 compliant and 10% Tier 3 compliant.

Fuel Composition

The extent and composition of diesel exhaust emissions is not only dependent on the emission performance of engines and equipment but also on operational factors and fuel composition. In Australia, *through the Fuel Quality Standards Act (2000)*, the mandatory automotive diesel oil (ADO) specification for sulfur has been reduced from 5,000 ppm to 500 ppm, to 50 ppm and more recently (January 2009) to 10 ppm.

Although it is speculated that off-specification diesel is not widely used by large mining and industrial fleets, the potential exists that some non-road diesel engine/equipment applications are operated using such fuel.

It has also been postulated that the increasingly stringent sulfur specifications and raised excise have reduced the road transport diesel fuel market for used oil derived diesel fuels. Fuel uses such as stationary engines, non-road vehicles, marine propulsion engines, and

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10 Power generation sets comprise engines in which are actually sold as a power generator set, not as a bare or loose engine.
11 Power generation drives are engines sold for the manufacture of generator sets.

construction and mining equipment used in remote environments have been highlighted as possibly sustaining the market for recycled fuel products with sulfur levels greater than 50 ppm.

If high sulfur content diesel fuel remains commercially available for non-road applications, it will have a significant negative impact if used for engines equipped with after treatment, and on engines using oils that are not developed for elevated fuel sulfur operation.

Australian Market for Cleaner Non-road Diesel Engines/Equipment

A survey of non-road diesel equipment user attitudes towards the uptake of cleaner non-road diesel engines and equipment was undertaken to inform this study. The main aim of the survey was to determine consumer and industry stakeholder readiness for cleaner products. Thirteen companies with significant non-road diesel applications participated in the survey, including companies from the following industry sectors: construction (4), mining (2), ports (2), airports (1), waste (1), and manufacturing (3).

Most companies are not familiar with US and EU emission limits for non-road diesel . In cases where knowledge is held, this is mainly based on information provided by non-road diesel equipment suppliers.

Although the purchasing behaviours of some companies include non-road diesel emissions performance considerations, none of the companies surveyed had specific documented policies governing the purchase of low emission non-road diesel equipment. Furthermore, the control of emissions from non-road diesel engines/equipment are typically not included in the air quality management plans of companies.

Some companies that are large scale non-road diesel equipment users have undertaken specific actions to address air emissions from such equipment (despite not including these sources formally in their air quality management plans). These actions tend to focus on fuel use and maintenance practices, where other benefits such as improved fuel efficiency, productivity and, possibly, safety considerations are likely to be major drivers.

Where equipment operates indoors, the need to reduce occupational exposure potentials has been a driver in the selection of cleaner equipment (e.g. battery-electric forklifts). The choice of engine and supplier is rarely used as a means to manage air emissions from non-road diesel equipment in the absence of other significant drivers.

The main reasons identified for non-road diesel equipment emissions not being subject to further controls by companies are as follows:

- Non-road diesel equipment are not regulated through Environment Protection Licences and represent a minor source of air emissions compared to the major point and fugitive sources being managed by companies.
- Lack of information on the air emissions performance of non-road diesel equipment on the market.

- Lack of best practice guidance on managing emissions from non-road diesel equipment.
- Absence of financial incentives to control non-road diesel equipment emissions or encourage moves towards cleaner alternatives.

Companies generally seem open to cleaner non-road diesel alternatives. In terms of the most effective and acceptable methods of realising reductions in air emissions from non-road diesel equipment, companies tended to support one of the following options:

- Combination of guidelines, improved information and financial incentives.
- Use of mandatory measures, either in isolation or in addition to improved information and financial incentives.

Emission Reductions and Health Benefits of Compliance with International Standards

To assess the potential benefits of non-road diesel emission management, emissions were estimated for new (and imported used) non-road diesel engines/equipment sold into the Australian market during the 2009 to 2030 period, excluding emissions due to in-service equipment in place by 2008.

Emissions were projected for selected years, namely 2009, 2020 and 2030. Given the growth in the population of post-2008 engines/equipment, and the scrappage of the current in-service engines/equipment population, post-2008 units are projected to comprise the bulk of the total population by 2030. Whereas emission projections for 2009 and 2020 are indicative of a portion of the total non-road diesel related emissions, *emission estimates for 2030 are expected to be more representative of the total non-road diesel population*.

Emission projections were undertaken for base case (business as usual) and regulated (adoption of US/EU standards in Australia) emission scenarios. Differences between base case and regulated case emissions reflect the emission reductions achievable through the implementation of international standards. Due to uncertainties regarding future changes in the emission performance of non-road diesel engines upper and lower bound base case scenarios were defined as follows:

- **Upper bound (conservative) base case scenario** – assuming the emission performance status of engines/equipment inventoried for 2008 would remain representative of the emission performance status of the engines/equipment sold into Australia during the 2009 to 2030 period.
- **Lower bound (best case) base case scenario**. This scenario is based on the premise that there may be a gradual improvement in the overall emission performance of non-road diesel engines/equipment over time, as documented further in the report.

The **Control Scenario** was defined to assess maximum emission reductions achievable through the implementation of emission standards equivalent to those implemented in the US.

Key assumption and limitations for the emission projections are documented in the main body of the report.

Base Case Emissions:

- The total non-road diesel population (in terms of new and imported used engines/equipment sold into Australia after 2008) is estimated to be about 454,000 units by 2020. This population is projected to increase to 616,000 by 2030, at which time post-2008 units will make up the bulk of the in-service population.
- Annual PM_{10} emissions due to non-road diesel engines/equipment were projected to be in the range of 7.8 kilo-tonnes per annum (ktpa) to 14.6 ktpa by 2030 given base case (business as usual) operations, with 97% of such emissions being $PM_{2.5}$. Annual NO_x emissions are estimated to be in the range 82.6 ktpa to 117.4 ktpa.
- Heavy Industrial (construction, mining) Equipment is projected to contribute most to non-road diesel emissions, representing over 50% of PM_{10}, $PM_{2.5}$, CO and NO_x emissions and 45% of VOC emissions by 2030.
- Agricultural Equipment accounts for about 24% of PM emissions by 2030. Agricultural tractors were estimated to account for over 80% of all agricultural sector PM emissions.
- Equipment which have ratings greater than 56 kW account for 88% of total PM emissions, despite only accounting for about 50% of the total number of engines.
- Small engines (below 19 kW) are estimated to contribute about 2% of total PM emissions, despite accounting for almost a quarter of the total number of engines.

Emission Reduction Achievable given Compliance with International Standards:

- Given stringent controls (i.e. implementation of US Tier 4 emission standards), annual PM_{10} emission reductions are estimated to be in the range of 5.6 ktpa to 10.2 ktpa in 2020, increasing to 7.3 ktpa to 14.1 ktpa by 2030.
- Controls were estimated to result in annual NO_x emission reductions of between 44.1 ktpa and 65.6 ktpa by 2020, and in the range of 57.4 ktpa to 92.3 ktpa by 2030.
- The greatest PM emission reductions are achievable from Heavy Industry (Construction, Mining) (55%), followed by Agriculture (25%), General Industry (13%) and Power Generation Sets (7%).
- The control of larger (above 56 kW) engines/equipment accounts for 88% of the overall potential PM emission reductions from the non-road diesel sector.
- Small engines (below 19 kW) are estimated to account for about 2% of the overall PM emission reductions (i.e. 320 tpa reduction), with very small engines (below 8 kW) responsible for 0.1% of the overall reductions (i.e. reduction of 20 tpa).

Prioritisation by Power Rating Class for Potential Regulation:

Non-road engines may be manufactured for use in a range of non-road equipment and applications, prioritisation of power rating classes within the Australian context for potential regulation is therefore pertinent. Based on the extent of PM emission reductions achievable, the predefined power rating classes were ranked as follows (from highest to lowest priority, with percentage of total PM_{10} emission reduction achievable noted):

Ranking	Power Rating Class (kW)	% of Total PM_{10} Emission Reductions
1	56 – 130	51.7
2	130 – 560	21.0
3	>560	15.5
4	37 – 56	5.4
5	19 – 37	4.1
6	8 – 19	2.1
7	<8	0.1

Market Sub-sectors for Potential Non-regulatory Measures

- Two market sub-sectors were identified for consideration for potential implementation of non-regulatory measures based on the particulate emission reductions achievable, namely Heavy Industrial (Construction, Mining) Engines/Equipment and Power Generation Sets.

- The introduction of effective emission reduction measures within the Heavy Industrial (Construction, Mining) Engine/Equipment sub-sector was estimated to be able to achieve the most significant overall reduction in non-road diesel related PM_{10} emissions (i.e. 55% of total PM_{10} emission reduction achievable).

An example of a potential non-regulatory measure is a Memorandum of Understanding (MOU) with engine manufacturers in which such manufacturers agree to produce engines which are compliant with specified emission standards.

Environmental (Health) Benefits of Emission Reductions

Taking into account emission reductions projected given compliance with best practice emission standards, and published unit external costs for NO_x and PM_{10}, annual environmental (health) benefits are estimated to be in the range \$2.5 to \$4.7 billion (2008 AUD) by 2030.

Emission Management Options for Australia

A preliminary, qualitative assessment was undertaken of the applicability, within the Australian context, of identified non-road diesel emission reduction measures and product lines targeted by international standards. Factors taken into account in the assessment included emission reductions achievable, administrative ease of measure, urban/rural impacts, stakeholder readiness, and the consideration of additional benefits. A range of measures were considered including:

- 'Business as usual' (i.e. no action by government).
- Product-based Emission Reduction Measures – including: explicit government regulation, co-regulation, quasi-regulation and self regulation comprising voluntary initiatives, recognition programs and industry benchmarking.

Fuel quality management measures were also considered.

Nationally, non-road diesel engines are estimated to contribute PM_{10} emissions and significant NO_x emissions of the same magnitude as the on-road (petrol and diesel) vehicle sector which has been subject to increasingly stringent regulation. Given the estimated significance of non-road diesel engine/equipment emissions, and projected increases in the extent of such emissions given 'business as usual', government action seems warranted.

Preferred Approach

The establishment of non-road diesel regulations based on existing overeseas standards is the preferred approach to effectively address emissions from this sector. Consideration of national non-road diesel emissions regulations would require a regulatory impact assessment be conducted, which includes a detailed cost benefit analysis to assess the merits of regulation and involve thorough stakeholder consultation on possible options.

In line with international trends any such regulations should specify emission standards by engine rating class and have broad coverage, including as a minimum engines/equipment with 19 kW to greater than 560 kW power ratings.

Given that the specific locations of engine/equipment applications are not known it is important that the cost benefit analysis consider urban and rural impacts. Options that could be considered in the cost benefit analysis include:

- Excluding small engines i.e. 0 to 8 kW engines and consideration of excluding engines/equipment in the 8 to 19 kW. A significant proportion of agricultural equipment falls into these categories. The smallest engines (less than 8 kW) are estimated to contribute less than 0.1% of total PM emissions and engines less than 19 kW are estimated to account for just over 2%. Agricultural pumps and irrigation applications are dominated by small engines (76% less than 8 kW; 80% less than 19 kW). The average power rating of agricultural tractors sold is of the order of 60 kW, with about 20% of tractors being smaller than 19 kW.

- Excluding all agricultural tractors as generally agricultural applications take place in remote areas. (Note any loose engines later installed in tractors may not be covered by this option).
- Impacts on the mining sector could also be considered as mining applications can take place at remote locations or conducted in close proximity to metropolitan areas. However, given the high level of compliance of mining engines and equipment with an existing US or EU standard it is likely the sector would experience minimal impacts from formal adoption of emission standards.

It is recommended that any proposed non-road diesel regulations be harmonised with US and/or EU regulations in terms of engine rating classes, emission standards and compliance testing protocols. Compliance timeframes should however be tailored to reflect local circumstances, with progressive implementation of more stringent emission limits to minimise potential economic impacts and maximise compliance with regulations. Maximum emission reductions achievable were demonstrated during the current study by assuming compliance with Tier 4 standards in the short- to medium-terms. To allow local industry additional time to adjust to new policy requirements less stringent standards could be considered in the short-term and progression proposed towards the adoption of more stringent standards (e.g. implementation of Tier 2 equivalent standards by 2012, Tier 3 equivalent standards by 2020, and Tier 4 equivalent standards in subsequent years).

It is recommended that consideration be given to regulating the quality of diesel being used for non-road applications in Australia. This could be implemented through a requirement that diesel meeting the ADO fuel standard must be used for non-road applications, or through the development of an additional fuel standard for non-road applications.

Additional Short-term Approach

The establishment of one or more industry-government partnerships (quasi-regulation), focusing on targeted non-road diesel engine/equipment sectors would be beneficial in the short-term (in the event that the regulatory development process is lengthy).

The Heavy Industrial (Construction, Mining) Engine/Equipment sector represents a feasible target for such an approach given that suppliers of such engines/equipment appear more organised and progressive, and significant reductions in PM_{10} emissions could be achieved through improved emission performance.

Depending on the outcome of preliminary industry consultations, it may be beneficial to limit coverage to larger (above 37 kW) heavy industrial (construction, mining) equipment, thus reducing the number of units being managed without substantially affecting the emission reduction achievable in densely populated areas.

The commitment to progressive reduction of emissions can be reflected in a Memorandum of Understanding, with Construction, Mining Equipment Industry Group (CMEIG) to provide aggregated sales figures periodically, including information on the emission performance status of products sold.

1 Introduction

1.1 Background Information

Ambient Air Quality National Environmental Protection Measure (AAQ NEPM) goals for fine particles are exceeded nationally within various urban and rural environments, including parts of regional NSW[(12)]. Fine particles with an aerodynamic diameter of under 10 micron (PM_{10}) are of greatest concern in terms of health risks due to their being small enough to be inhaled and remain within the respiratory system. Very fine particles of 2.5 microns or less ($PM_{2.5}$) have been found to pose the greatest health risk as these particles are more readily deposited in, and damaging to, the lower airways and gas-exchanging portions of the lung.

Adverse health effects related to fine particulate matter inhalation include exacerbation of existing pulmonary disease, oxidative stress and inflammation, changes in cardiac autonomic functions and reduced defence mechanisms and lung damage[(13)]. Significant health costs are associated with inhalation exposures to fine particulate matter[(14)]. The main anthropogenic sources of fine particles have been found to be motor vehicles (especially diesel-fuelled vehicles), industry, and the commercial and domestic sector (notably solid fuel heaters). Health studies fail to demonstrate a threshold concentration for exposure to PM, below which health impacts are not observed, and there are adverse impacts associated with exposure to PM below AAQ NEPM PM standards. Therefore, there are significant community health benefits associated with reducing PM levels as much as practicable, even in regions where air quality standards are met.

AAQ NEPM goals for ozone are exceeded within several Australian cities including Sydney and Wollongong. Ozone exposures can induce serious respiratory tract responses including lung function reductions, aggravation of pre-existing respiratory disease (such as asthma), increases in daily hospital admissions, emergency department visits for respiratory causes, and excess mortality[(15)]. As for PM, health studies fail to demonstrate a threshold concentration for exposure to ozone.

The contribution of non-road engines to total anthropogenic NOx (a precursor of photochemical smog notably ozone) and fine particulate emissions have been concluded by previous national and state studies to be worthy of further consideration[(16)(17)]. The national study concluded that the introduction of management programs for these emissions would appear to be justified.

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12 NSW DECCW (2007). Current and Projected Air Quality in NSW, A Technical Paper Supporting the Clean Air Forum 2007, Department of Environment, Climate Change and Water.
13 Pope III C.A. and Dockery D.W.C. (2006). Health Effects of Fine Particulate Air Pollution: Lines that Connect, Journal of Air & Waste Management Association, 56, 709-742.
14 BTRE (2005). Health Impacts of Transport Emissions in Australia: Economic Costs, Canberra, Bureau of Transport and Regional Economics.
15 WHO (2003). Health Aspects of Air Pollution with Particulate matter, Ozone and Nitrogen Dioxide, Report on a World Health Organisation Working Group, Bonn, Germany, 13-15 January 2003.
16 PAE (2005). Management Options for Non-road Engine Emissions in Urban Areas, Report compiled by Pacific Air and Environment on behalf of the Department of the Environment and Heritage, November 2005.
17 NSW DECCW (2007). Air Emissions Inventory for the Greater Metropolitan Region in New South Wales, New South Wales, Department of Environment, Climate Change and Water, Sydney.

Regulations for non-road (off-road) equipment have been introduced in a number of countries over the past 15 years, namely: the US (1994), Europe (1997), Canada (2005), Japan (2006), India (2006), China (2007). Such regulations are also either proposed for adoption (e.g. South Korea) or currently under consideration in several other countries (e.g. Brazil). Engine oxides of nitrogen (NO_x) emission standards for new stationary diesel engines have also been promulgated (2005) under the Gothenburg Protocol, which aims to abate acidification, eutrophication and ground-level ozone. These standards are applicable to a number of European countries.

The US Clean Diesel Rule passed in 2004 marked a shift towards the integration of engine and fuel control measures to optimise emission reductions from non-road diesel engines. When externalities such as avoidance of premature deaths and public health benefits are accounted for, the US EPA estimates that the benefits (savings, estimated at approximately US$80 billion/year) achievable through the implementation of its 2004 Clean Diesel Rule will outweigh costs (estimated at US$2 billion/year) by a ratio of 40 to 1 by 2030[(18)].

The first European legislation to regulate non-road mobile equipment emissions was promulgated in 1997[(19)], with regulations introduced in two stages (Stage I implemented in 1999 and Stage II implemented from 2001 to 2004). Stage I and II limits were partly harmonised with US Tier 1 and 2 regulations. More stringent (Stage III/IV) emission standards were adopted in 2004 (Directive 2004/26/EC), with Stage III standards phase in from 2006 to 2013 and Stage IV standards entering into force in 2014. Stage III and IV limits were intended by European regulatory authorities to harmonize with US Tier 3 and 4 emission standards.

Other initiatives to reduce emissions from non-road diesel engines have included voluntary and other management measures. Examples include: Canadian Memorandum of Understanding (MoU) with major engine manufacturers to produce engines complying with US emission standards (prior to promulgation of Canadian emission standards); US voluntary diesel retrofit program; Switzerland BUWAL particulate filter list – official list of approved particulate filter systems for retrofitting of construction vehicles; and California Air Resources Board (CARB) stationary diesel programs and measures for in-use diesel agricultural engines, stationary compression-ignition engines, portable diesel-fuelled engines.

Emission reductions achieved through the control of non-road engine emissions in the US and Europe have assisted in addressing local air quality problems in non-attainment areas over the past decade.

There are no regulations currently in place in Australia that limit allowable emissions from non-road diesel engines/equipment. However, Australia has benefited somewhat from US, EU and other emission standards, as many of the manufacturers that distribute to these markets also distribute to Australia.

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18 US-EPA (2004). Final Regulatory Analysis: Control of Emissions from Non-road Diesel Engines, EPA-420-R-04-007, May 2004.
19 European Commission Directive 97/68/EC, Approximation of the laws of the Member States relating to Measures against the Emission of Gaseous and Particulate Pollutants from Internal Combustion Engines to be Installed in Non-road Mobile Machinery.

Concerns have also been raised regarding potential increases in emissions if equipment manufactured in countries with less stringent or no emission limits increase their market share in Australia.

Reducing emissions from mining, construction and other sectors that use large non-road diesel engines would assist in reducing health risks associated with particles, air toxics and ozone. It is anticipated that this would deliver significant public health benefits in Australia.

1.2 Study Objective

In August 2008, the Environment Protection and Heritage Council Air Quality Working Group endorsed a project to gather information on non-road diesel engines in Australia and scope possible actions to manage emissions from these engines. The NSW and the Australian Government agreed to jointly fund the scoping project. It was subsequently agreed that NSW Department of Environment, Climate Change and Water (DECCW) would manage this project.

ENVIRON Australia (Pty) Ltd (hereafter “ENVIRON”) has been commissioned by the NSW DECCW to undertake a project to identify and recommend measures to support the supply and purchase of cleaner non-road diesel engines so as to reduce the overall emissions from such engines in Australia.

The focus of the study is on the multiple non-road diesel engines market segments such as airport service equipment (e.g. terminal tractors, ground power units etc.); industrial equipment (e.g. aerial lifts, forklifts, sweepers, scrubbers etc.); construction equipment (e.g. excavators, cranes, graders, etc.); mining and agricultural equipment. International and interstate commercial marine and diesel locomotive sectors are not included in the scope of the study.

The project is intended to provide NSW DECCW with informed advice on:

- *Characteristics of the non-road diesel engine market in Australia* - inventory of number, types, country of origin, emission performance (etc.) of engines currently being sold within Australia; purchasing behaviours of large consumers in respect of cleaner engines; and potential niche markets.

- *Levels of emissions from non-road engines* – including the quantification of emissions from new engines, and integration and potential extrapolation of findings from previous studies quantifying emissions from in-service engines, and the contribution of this sector to total antropogenic emissions of key pollutants.

- *Potential measures that will result in the increased uptake of less polluting non-road diesel engines* – with consideration of: measures targeting supply and demand; voluntary and mandatory measures; differentiation of measures based on engine size, sector implementation; phasing in of measures; and the ‘packaging’ of measures.

Specific advice on the most constructive course or courses of action represents a critical outcome of the project.

1.3 Scope of Works

The specific terms of reference of the project are as follows:

- Characterisation of the non-road diesel engines/equipment sold in Australia and NSW by emissions performance relative to established United States and European standards.
- Characterisation of the NSW and Australian market for the product sector based on the review of existing data and consulting key stakeholders to determine:
    - Consumer and industry stakeholder readiness for cleaner products (based on current knowledge, attitudes, purchasing behaviours etc);
    - Any obvious niche markets that may be amenable to a targeted voluntary scheme;
    - Products that may be a focus of measures; and
    - Gaps in information / recommendations on additional research needed before developing and implementing management policies.
- Assessment of voluntary and mandatory initiatives used overseas such as labelling and introduction of standards, and evaluation of their applicability in Australia. Provision of an overview of the effectiveness of options such as diesel retrofits for in-service non-road engines.
- Assessment of potential emission reductions achievable through compliance with overseas standards.
- Assessment of the national contribution of non-road diesel for major pollutants, both as a total mass and as a percentage compared to other anthropogenic emissions such as the road transport sector.
- Provision of recommendations to manage emissions for the non-road diesel sector including, where appropriate, targeted measures to address emissions from specified product lines.

The focus of the study is predominantly on new non-road diesel engines, with emphasis on the characterization of new engines supplied/purchased, emissions from such engines, and measures and associated emission reduction potentials applicable to new engines. An overview is however provided on the effectiveness of operations such as diesel retrofits, which hold relevance for in-service non-road engines.

1.3.1 Market Segments / Equipment Categories

This study focusses on non-road diesel engine market segments (and engine sizes and type categories) which have been targeted in US and EU non-road diesel engine regulations. Engine/equipment categories of interest are as follows:

- Airport Service Equipment, e.g. ground support equipment including ground power units, air climate units, aircraft tugs, conveyor belts, passenger stairs, fork lifts, tractors and cargo loaders, and auxiliary power units.

- Industrial Equipment, e.g. aerial lifts, drill rigs, bulldozers, chippers, cranes, crushing equipment, excavators, forklifts, generators, graders, loaders, off-highway trucks, pumps, rollers, rubber tyre loaders, scrapers, skid steer loaders, sweepers, scrubbers, tractors, loaders, backhoes.

- Construction Equipment, e.g. asphalt pavers, rollers, scrapers, dozers, concrete and industrial saws, cranes, crushers, excavators, forklifts, graders, non-road tractors, non-road trucks, plate compactors, loaders, tampers and rammers, backhoes, trenchers.

- Mining Equipment, e.g. loaders, scrapers, dozers, non-road trucks, generators, drilling rigs, compressors.

- Agricultural and Forestry Equipment, e.g. tractors, combines, harvesters, chain saws.

- Commercial Equipment, e.g. aerial lifts, bulldozers, cranes, excavators, forklifts, loaders, off-highway trucks, rubber tyre loaders, skid steer loaders, tractors, backhoes.

- Marine – excludes international and interstate commercial marine but including engines for inland water vessels.

Marine, aircraft and locomotive engines have typically been excluded in the US from non-road diesel engine regulations, being covered by other sets of emission standards. However, the US and EU both cover smaller diesel marine engines. The US emission standards for non-road diesel engines less than 37 kW under Tier 1 and 2 of the Rule do include marine engines in this size range and the EU Stage III/IV standards adopted in 2004 include marine engines used for inland waterway vessels. It is for this reason that small (below 37 kW) marine engines are included in the scope of this study.

1.4 Study Overview and Report Outline

Non-road diesel engine types and applications were inventoried (**Section 2**), taking into account engine power rating classes and applications covered by non-road diesel emission standards abroad.

An assessment was undertaken of the significance of in-service non-road diesel engine/equipment emissions (**Section 3**). This assessment comprised the review of previous studies, a qualitative analysis of diesel engine emission characteristics and the health and environmental impacts of such emissions, and the quantitative estimation of emissions from the in-service non-road diesel equipment population. Non-road diesel equipment emissions were compared to on road vehicle emissions.

In selecting non-road diesel emissions standards for review during the study, factors taken into account included: countries from which engines are imported into Australia; widely referenced emission standards, and regulatory regimes which are frequently referenced in Australia. Based on these considerations, and taking into account the availability of emissions standards, the following standards were referenced in the study: US Federal, European Union (EU), China, Japan and India (**Section 4**).

To characterise the non-road diesel engines and equipment sold into Australia reference was made to previous studies, and to market share information and sales data available from sources such as the Construction, Mining Equipment Industry Group (CMEIG), the Australian Bureau of Statistics (ABS) and ERG International. Emission performance information for specific non-road diesel engine/equipment brands and models were acquired through consultation with major engine and equipment manufacturers, importers and distributors. An overview is provided of the size and diversity of the Australian non-road diesel product market in **Section 5**, and the emission performance status of products sold during 2008 described.

The characterisation of the market for cleaner non-road diesel engines/equipment was based on the review of available information and through structured consultation with key stakeholders (**Section 6**). This consultation took the form of a project-specific survey of a number of large users of non-road diesel equipment across several market sectors. The survey was designed to determine consumer and industry stakeholder readiness for cleaner products.

A review was undertaken of international and local measures for reducing emissions from new non-road diesel engines and equipment (**Section 7**). Attention was paid to voluntary and mandatory measures implemented in North America (US, Canada), Europe (EU) and Asia (Japan, Singapore, China). The study primarily focused on measures for new equipment. For in-service non-road engines an overview of the effectiveness of options such as diesel retrofit programs is provided. The applicability of internationally targeted products and associated measures for Australia was qualitatively assessed taking into account locally significant product types and other contextual information.

Emissions associated with new non-road diesel engines/equipment sold in Australia during 2008 were estimated using emission performance information obtained from suppliers, specifically information related to the compliance of such engines with overseas emission standards (**Section 8**). Emissions were estimated for particulates (TPM, PM_{10}, $PM_{2.5}$), oxides of nitrogen (NO_x), total volatile organic compounds (VOCs), benzene, formaldehyde, acetaldehyde, 1.3-butadiene and acrolein. The potential for emission reductions achievable through compliance with international standards was quantified to inform the analysis of possible benefits from managing non-road diesel engine emissions.

Possible emission management measures for non-road diesel engines within the Australian context were reviewed taking into account: emission reduction potentials, costs and administrative ease of measures, stakeholder readiness and other benefits (e.g. fuel consumption). Recommendations are made in respect of measures suitable for consideration within Australia for the management of emissions from new non-road diesel products (**Section 9**).

2 Non-road Diesel Engines and their Applications

A description of diesel engine technology is given in this section, with an overview provided of non-road diesel engine applications. Non-road diesel engine applications which are generally included in regulations abroad are highlighted.

2.1 Diesel Engine Technology

2.1.1 Engine Configuration

A diesel engine is an internal combustion engine which uses the heat of compression to initiate ignition to burn the fuel which is injected into the combustion chamber during the final stage of compression. This is in contrast to a petrol engine or gas engine in which a fuel/air mixture is ignited by a spark plug.

The compression-ignition combustion process depends on the fuel characteristics, combustion chamber design and fuel-injection system and the engine's operating conditions.

Air is introduced into the combustion chamber of the diesel engine and then the high compression heats the air to 550°C, following which fuel is injected directly into the compressed air in the combustion chamber. The manner in which this is done is dependent on the diesel engine combustion chamber design:

- direct-injection (DI) engines have a single open combustion chamber into which fuel is injected directly;
- indirect-injection engines (IDI) have divided chambers and the fuel is injected into the prechamber which is connected to the main chamber via a nozzle or one or more orifices. IDI engine designs are only used in the smallest engine sizes.

Within each engine category there are several different chamber geometry, air-flow and fuel-injection arrangements.

Both mechanical and electronic injection systems can be used in either direct or indirect injection engine configurations. The electronic injection system has a solenoid operated by an electronic control unit, resulting in more accurate control of injector opening times that depend on other control conditions such as engine speed and loading. Electronic injection systems provide better engine performance and fuel economy.

Older diesel engines with mechanical injection pumps could be inadvertently run in reverse, albeit very inefficiently, as evident by massive amounts of soot being ejected from the air intake.

Indirect injection engines were used in small-capacity, high-speed diesel engines in automotive, marine and construction uses from the 1950s, until direct injection technology advanced in the 1980s. Indirect injection engines are cheaper to build and it is easier to produce smooth, quiet-running vehicles with a simple mechanical system. In road-going vehicles most prefer the greater efficiency and better controlled emission levels of direct injection.

Diesel engines are manufactured in two stroke and four stroke versions. The four-stroke type is the most commonly used form, being the preferred power source for many motor vehicles, especially buses and trucks and non-road mobile equipment. Much larger engines, such as used for railroad locomotion and marine propulsion, are often two-stroke units, offering a more favorable power-to-weight ratio, as well as better fuel economy.

Most diesels are now turbocharged and some are both turbo charged and supercharged. Turbocharged engines can produce significantly more power than a naturally aspirated engine of the same configuration. A supercharger is powered mechanically by the engine's crankshaft, while a turbocharger is powered by the engine exhaust, not requiring any mechanical power, hence turbocharging does not adversely affect the fuel economy.

2.1.2 Fuel Characteristics

Depending on their configurations diesel engines can operate on a variety of different fuels. Diesel fuel, a form of light fuel oil very similar to kerosene which is derived from crude oil is the most commonly used. Diesel engines can work with the full range of crude oil distillates, from natural gas, alcohols, gasoline, wood gas, to the fuel oils from diesel oil to residual fuels. Good-quality diesel fuel can be synthesised from vegetable oil and alcohol. Diesel fuel can be made from coal or other carbon base using the Fischer-Tropsch process. Biodiesel is a pure diesel-like fuel refined from vegetable oil and can be used in nearly all diesel engines.

National fuel quality specifications are determined by the Commonwealth fuel quality standards act. Their applicability to non-road diesel engines is discussed at Section 3.15.

Most large marine diesels run on heavy fuel oil (bunker oil), which is a thick, viscous and almost un-flammable fuel which is very safe to store and cheap to buy in bulk as it is a waste product from the petroleum refining industry. The fuel must be heated to thin it out (often by the exhaust header) and is often passed through multiple injection stages to vaporize it.

Residual fuels are the "dregs" of the distillation process. Residual fuel oils are cheaper than clean, refined diesel oil, although they are dirtier. Their main applications are in ships and very large generation sets, due to the cost of the large volume of fuel consumed, frequently amounting to many tonnes per hour.

2.2 Diesel Engine Applications

Non-road diesel engines types and applications were inventoried based on a range of information sources including the following:

- NSW DECCW Air Emissions Inventory for the Greater Metropolitan Region in New South Wales, Off-Road Mobile Emissions Module (2007).
- National Pollutant Inventory (NPI) aggregated emissions data (AED) sources.
- US-EPA AP42 Compilation of Air Pollutant Emission Factors.
- US-EPA Emission Inventory Improvement Program (EIIP) reports.

- Non-road diesel engine regulations issued by the US, EU, Japan, Singapore, China and India.
- Consultation with ADEDA, CMEIG and TMA representatives.

Non-road diesel engines and equipment are used in a wide variety of applications including construction, farming, industrial, and airport services. Unlike on-road vehicles, the non-road diesel category applies to a very broad range of engine sizes, types of equipment, and power ratings.

Diesel engine horsepower ranges from 1 to over 1,000 kW. The equipment in which the engines are used is extremely diverse, with often the same engine being used in widely varying equipment applications. For example, the same engine used in a backhoe can also be used in a drill rig or in an air compressor.

Approximately 50 companies manufacture non-road diesel engines worldwide[(20)]. Many companies involved in the non-road diesel industry are not "vertically integrated"; that is, they do not produce both engines and the equipment applications that the engines are used in. The implications of this have been that emission management measures adopted abroad need to address the ability of both engine manufacturers and equipment manufacturers to provide adequate new non-road machines

The applications of non-road diesel engines vary broadly depending on the size of the engine. Common applications for each of the major non-road diesel engine size categories are given in **Table 2** .

Table 2: Common applications for various non-road diesel engine size categories

Non-road Diesel Engine Size Categories	Common Applications
0 to 30 kW	Refrigeration/air-conditioning units, commercial mowers, mobile welders
30 to 100 kW	Bulldozers, fork lifts, agricultural tractors
100 to 250 kW	Tractors, backhoes, excavators
250 to 1000 kW	Tractors, combines, road graders
Above 1000 kW	Generator sets, off-highway trucks, crawlers

Diesel engines are typically classified by engine manufacturers and suppliers according to their application.

20 US-EPA (2004). Final Regulatory Analysis: Control of Emissions from Non-road Diesel Engines, EPA-420-R-04-007, May 2004.

A summary of the market segments and application categories for which diesel engines are used is provided in Error! Reference source not found.. Reference is only made in the table to diesel engines/equipment which are most typically included in engine regulations abroad.

Diesel engines/equipment which are excluded on the grounds of being regulated under other classes of regulation include: aircraft, diesel locomotives, and large sea-going marine vessels.

Table 3: Market segments and application categories for non-road diesel engines/equipment which are typically included in non-road diesel regulations abroad

Market Segment	Applications		
Agriculture	Agricultural tractors	Combine harvesters and seeders	Other agricultural equipment
	Self propelled sprayers	Cherry pickers/orchard harvesters	
	Windrower tractors	Grain shifters	
Construction and Mining(a)	Pavers	Bore/drilling rigs	Excavators
	Tampers/rammers	Rough terrain forklifts	Cranes
	Plate compactors	Underground mine loaders	Graders
	Off highway tractors	Trenchers	Dumpers/tenders
	Off highway trucks	Wheeled loaders	Crawler tractors
	Portable compressors	Wheeled dozers	Skid steer loaders
	Surfacing equipment	Scrapers	Rollers
	Backhoe loaders	Crushing/processing equipment	Crawler dozers/loaders/tractors
	Underground mine vehicles	Other construction equipment	
General Industrial	Aerial lifts	Refrigeration/AC	Concrete pumping equipment
	Forklifts	Concrete/Industrial saw	Oil and gas processing equipment
	Sweepers/scrubbers	Crushing Equipment	Other general industrial equipment
	Generator set, welder	Signal board	
Lawn and Garden	Lawn and garden tractors	Commercial mover	Chippers/stump grinders
	Rear engine riding mowers	Wood splitters	
Airport Service Equipment	Ground power unit (GPU)	Passenger stairs	Catering/service truck
	Air conditioning / heater unit	Belt loader	Lavatory truck; potable water truck
	Air starter unit	Baggage tug / tractor	Fuel hydrant truck
	Narrow-body push out tractor	Cargo and container loader	Fuel tanker truck
	Wide-body push out tractor	Cargo delivery	Maintenance lift
	Passenger buses	Bobtail Truck	Miscellaneous vehicles (cars, vans, trucks)
	Fork lift		
Recreational Marine(b)	Pleasure cruisers	Pleasure fishing boats	Yachts / motor sailors
Commercial Marine(b)	Charter vessels	Patrol boats	Commercial fishing vessels & trawlers
	Ferries, tugs & barges		
Pumps and Compressors (Light Commercial Equipment)(c)	Air compressor	Pump	Pressure washer
	Hydro Power unit	Gas Compressor	Irrigation pumps
Power Generation(c)	Prime power	Standby power	Marine auxiliary
Logging Equipment	Chainsaws	Shredders	Fellers
	Skidders		

(a) US non-road diesel engine emission regulations exclude underground mining equipment.

(b) US non-road diesel engine emission regulations only include marine engines below 37 kW (50 hp). EU non-road mobile machinery emission regulations include only 'inland water vessels' of specific sizes and applications (Refer to Section 4).

(c) Depending on the power rating of the engines, a fraction of the applications indicated in the table such as air compressors, generator sets, hydropower units, irrigation sets, pumps and welders may be classified as stationary sources and therefore not subject to the US non-road diesel engine emission standards.

2.3 Summary of Findings

Non-road diesel engines and equipment are used in a wide variety of applications including construction, farming, industrial, and airport services. As a result of technological developments and the range of applications catered for, diesel engine configurations on the market vary significantly in terms of combustion chamber design, fuel-injection system, engine size and power rating. The diversity of applications is also reflected in the range of fuel characteristics and engine operating conditions evident for in-service engines. All of these factors affect the atmospheric emission potential of non-road diesel engines.

Equipment in which the engines are used is extremely diverse, with often the same engine being used in widely varying equipment applications. This has implications in terms of targeting specific engines/applications for emissions management.

Many equipment manufacturers buy in rather than manufacture the diesel engines which are incorporated into their equipment. This implies that emission management measures need to address the ability of both engine manufacturers and equipment manufacturers to provide the new non-road machines required under such measures.

3 Air Quality Impacts of Non-road Diesel

A key component of the study comprises the assessment of the significance of in-service non-road diesel engine/equipment emissions based on the review and revision of information provided in previous studies. To assess emissions and the magnitude of impacts from the in-service non-road diesel sector, this chapter provides information on:

- Diesel engine emissions characteristics (**Section 3.1**)
- Health and environment impacts associated with diesel emissions (**Section 3.2**)
- Estimates of national in-service non-road engine emissions (**Section 3.3**)
- Comparison of the contribution of national non-road diesel engine emissions to on road vehicle emissions (**Section 3.4**)
- Extrapolation of non-road diesel engine emissions by state and territory (**Section 3.5**)
- Case study of the contribution of non-road diesel emissions to NSW GMR Emissions (**Section 3.6**)

3.1 Diesel Emissions

Non-road diesel engine and equipment exhaust consists of hundreds of gas-phase, semi-volatile and particle-phase organic compounds that are produced through fossil fuel combustion. Emissions of primary and secondary particulate matter (PM) are of specific concern due to air quality criteria for fine PM being exceeded within several Australian metropolitan and rural areas. Oxides of nitrogen (NO_x) and volatile organic compound (VOC) emissions released from engine/equipment exhausts are of interest individually and due to their being precursors of photochemical smog including ozone. Other emissions associated with non-road diesel engines and equipment include carbon dioxide (CO_2), carbon monoxide (CO), carbonyl compounds (e.g. formaldehyde, acetaldehyde), polycyclic aromatic hydrocarbons (PAH), dioxins and furans, and a range of individual volatile and semi-volatile organic compounds including toxics such as benzene, toluene and 1,3-butadiene.

The exact composition of emissions depends on operational parameters such as speed, motor load, and engine and equipment type, in addition to fuel composition, ambient air temperature and relative humidity. For example, increasing the cetane index (indicative of fuel auto-ignitability) and reducing the aromatic content of fuel results in lower emissions of NO_x, hydrocarbons, CO and particulate matter. Lowering the sulfur content of fuel reduces both the SO_2 and particulate sulfur emissions. Air temperature affects the way in which diesel exhaust mixes in the atmosphere, thus affecting the concentrations and composition of airborne particulate matter.

3.2 Health and Environmental Impacts

Fine particles with an aerodynamic diameter of under 10 micron (PM_{10}) are of greatest concern in terms of health risks due to their being small enough to be inhaled and remain within the respiratory system. Very fine particles of 2.5 microns or less ($PM_{2.5}$) have been found to pose the greatest health risk as these particles are more readily deposited in, and damaging to, the lower airways and gas-exchanging portions of the lung.

Adverse health effects related to fine particulate matter inhalation include exacerbation of existing pulmonary disease, oxidative stress and inflammation, changes in cardiac autonomic functions and reduced defence mechanisms and lung damage(21). Significant health costs are associated with inhalation exposures to fine particulate matter(22).

Diesel particulate matter (DPM) is considered to comprise a particularly significant health risk due to the particle size distribution and chemical composition of such particulates. DPM is dominated by fine and ultra fine particles, the composition of which may include elemental carbon with adsorbed compounds such as organic compounds (including potentially carcinogenic organic compounds such as PAHs), sulphate, nitrate, metals and other trace elements. The International Agency for Research on Cancer has concluded that diesel exhaust is a probable human carcinogen(23).

NO_x emissions from non-road diesel engines contribute to photochemical smog and notably ozone. Ozone exposures can induce serious respiratory tract responses including lung function reductions, aggravation of pre-existing respiratory disease (such as asthma), increases in daily hospital admissions, emergency department visits for respiratory causes, and excess mortality(24).

Environmental impacts associated with particulate and ozone concentrations include visibility reduction, impacts on crop productivity and ecosystem integrity, and damage to buildings and property (e.g. soiling of surfaces; deterioration of rubber, fabric, masonry and paint).

3.3 Emissions from In-Service Non-road Diesel Engines and Equipment

3.3.1 Estimation of In-Service Non-road Diesel Emissions

The PAE (2005) study is the most comprehensive analysis of national emissions from non-road engines to date(25). This report considerably updates the intial work undertaken in the 2005 study.

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21 Pope III C.A. and Dockery D.W.C. (2006). Health Effects of Fine Particulate Air Pollution: Lines that Connect, Journal of Air & Waste Management Association, 56, 709-742.
22 BTRE (2005). Health Impacts of Transport Emissions in Australia: Economic Costs, Canberra, Bureau of Transport and Regional Economics.
23 IARC (1989). IARC monograph on the evaluation of carcinogenic risk of chemicals to humans: diesel and gasoline engine exhaust and some nitroarenes. Vol 46. Lyon, France: International Agency for Research on Cancer.
24 WHO (2003). Health Aspects of Air Pollution with Particulate matter, Ozone and Nitrogen Dioxide, Report on a World Health Organisation Working Group, Bonn, Germany, 13-15 January 2003.
25 PAE (2005). Management Options for Non-road Engine Emissions in Urban Areas, Report compiled by Pacific Air and Environment on behalf of the Department of the Environment and Heritage, November 2005.

The emission estimation method applied represents an improvement of the non-road diesel engine emission estimates from the PAE (2005) study for the following reasons:

- More representative and current emission factors are applied, with transient adjustment and deterioration factors applicable for each equipment application taken into account[(26)].

- Use of engine/equipment attributes (e.g. average power ratings) and application characteristics (load factors; annual hours of operation) for products sold into the Australian market. In cases where no local data were available for input into emission calculations, reference was made to the most current default data provided in the US-EPA NON-ROAD MOBILE 2008 model.

- Emission performance information collated for engines/equipment sold in 2008 is taken into account, rather than assuming that all in-service non-road diesel equipment are non-compliant with international standards.

Emission factors used in the quantification of non-road diesel engine exhaust and evaporative emissions are given in **Appendix H**. Emission inputs used in the exhaust calculations for in-service engine/equipment sub-populations are given in **Appendix A.**

Despite the revised inputs adopted in the current study, reference was made to the in-service non-road diesel equipment population information from PAE (2005) [(27)]. To demonstrate the extent of emissions from non-road diesel engines/equipment most typically regulated under non-road diesel regulations, diesel locomotive and larger (greater than 37 kW) diesel marine engines (covered in the 2005 study) were excluded. The estimated in-service non-road diesel equipment population inventoried by PAE (2005) for 2003 is given by market segment in **Table 4**, with the total in-service non-road diesel population estimated to be of the order of 550,000 (2003).

Table 4: In-service non-road diesel equipment population. (Data for 2003 inventoried by PAE in 2005).

Market Segment	Non-road Diesel Population
Lawn and garden equipment	45,987
Airport service equipment	5,676
Recreational equipment	270
Light commercial equipment	29,045
Industrial equipment	18,658
Construction (and Mining) equipment	166,092
Agricultural equipment	281,040
Logging equipment	4,216
Commercial marine (5% assumed to be <37 kW)	777
Total	**551,761**

26 Exhaust emission factors are typically given for recently manufactured engines with few operating hours and are typically derived directly from laboratory measurements conducted on new or nearly new engines under steady state conditions (constant engine speed and load). Transient adjustment factors (TAF) are applied to account for in field operations which involve transient conditions (variable speed and load). Deterioration factors are applied to account for increased emissions as engines age.

27 PAE (2005). Management Options for Non-road Engine Emissions in Urban Areas, Report compiled by Pacific Air and Environment on behalf of the Department of the Environment and Heritage, November 2005.

In-service non-road diesel emission estimates for various market applications are given in **Table 5**. The most significant non-road diesel engine/equipment applications, in terms of both PM and NO_x emissions, were estimated to be Construction (including Mining) Equipment followed by Agricultural and Forestry Equipment.

In terms of PM_{10} emissions, Construction and Mining Equipment was estimated to account for 61% of emissions with Agricultural and Forestry applications responsible for 30%. The contribution of in-service non-road diesel applications to PM_{10} emissions is illustrated by market segment in **Figure 2**.

Construction and Mining equipment was estimated to be responsible for 56% of NO_x emissions, with Agricultural and Forestry equipment estimated to account for a further 33%.

Table 5: Revised in-service non-road diesel engine/equipment emission estimates

Application	Annual Emissions (tpa)			
	PM_{10}	SO_2(c)	VOC	NOx
Lawn and garden equipment	185.8	1.7	210.5	1,558.2
Airport service equipment	201.1	3.8	249.6	2,363.4
Recreational equipment	5.0	0.0	13.6	11.4
Light commercial equipment	262.6	1.0	273.0	1,582.1
Industrial equipment	605.3	8.6	628.8	6,236.4
Construction and mining equipment(a)	8,175.6	77.4	6,532.9	49,597.5
Agricultural equipment	3,622.7	37.8	2,908.8	27,883.9
Logging equipment	460.0	4.5	275.7	3,455.6
Commercial marine(b)	0.3	0.0	0.6	4.8
Total Non-road Diesel	13,518.5	134.8	11,093.7	92,693.2

(a) Includes mining equipment and heavy industrial equipment.

(b) About 5% of commercial boat diesel engine emissions, as inventoried in PAE (2005), were assumed to be from small (<37 kW) engines. This assumption was informed by information from the 2003 NSW Emissions Inventory, according to which only 10% of diesel-fuelled commercial vessels had engine sizes of less than 50 kW. Taking into account the lower emissions of smaller engines, the assumption that such engines contribute 5% of total inventoried emissions for diesel-powered commercial marine vessels is considered conservative.

(c) SO_2 emissions reflect reduction in diesel sulfur content to 10 ppm for the post January 2009 period.

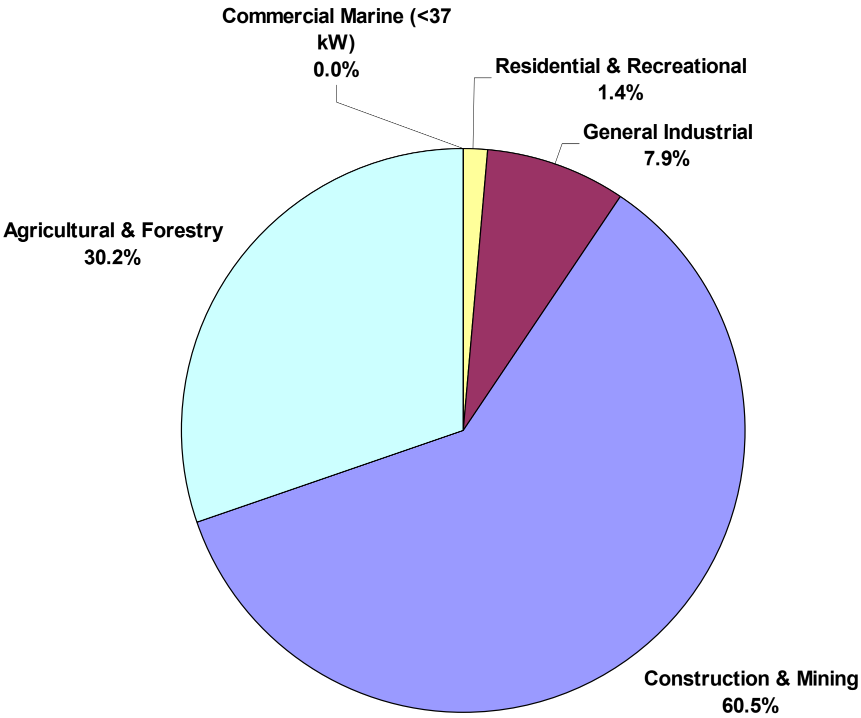

Figure 2: PM_{10} emissions from in-service non-road diesel equipment by market segment

3.3.2 Evaluation of Emission Estimate Accuracy based on Fuel Consumption

In this section, a validation of the emission estimates for total in-service non-road diesel engines is presented by comparing emission estimates developed in this study with emission estimates for sulfur dioxide based on national automotive diesel oil (ADO) fuel consumed and typical ADO sulfur contents.

The non-road diesel sector consumes a similar volume of ADO as the on-road diesel vehicle sector. In 2007-8, total ADO consumption is reported to be 17.8 gigalitres (GL), with about 46% of this being consumed by the road transport sector, and a further 8% used for rail, pipeline and marine transport[28].

The remaining 8.1 GL of ADO (45% of total consumption) is used in other non-road and non-water transport applications within the agriculture, forestry, fishing, manufacturing, construction, mining, commercial and electricity sectors. Mining and Construction was reported to consume about 47% of this ADO; Agriculture, Forestry and Fishing account for a further 25%, with the remainder being consumed by the Manufacturing (12%), Electricity (8%), Commercial/Services (7%) and Residential (<1%) sectors.

Sector-specific SO_2 emissions were calculated based on published 2007-8 ADO consumption rates, taking into account the post January 2009 fuel sulfur content of 10 ppm. These emissions were compared to the SO_2 emissions estimated on the basis of emission factors using estimated inputs in terms of equipment populations, annual operational hours,

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28 ABARE (2009). Energy in Australia 2009, Australian Government Department of Resources, Energy and Tourism.

engine power ratings and load factors (as documented in the previous subsection) (**Table 6**). The overall emissions and market sector contributions estimated using emission factors was found to compare with expected emissions given ADO consumption data.

Table 6: Comparison of SO_2 emissions from in-service non-road diesel usage based on recorded fuel consumption rates and emission factor application

Market Sector	Annual SO_2 Emissions (tpa) calculated based on Emission Factors(a)	Annual SO_2 Emissions (tpa) calculated based on ADO Consumption
Agriculture and Forestry	42.3	34.8
Construction and Mining	77.4	64.9
General Industry(b)	13.3	36.8
Residential	1.8	0.6
Marine (<37 kW)	0.004	ND
Total Non-road Diesel (in-service)	134.8	137.0

ND – no data

(a) Using as inputs estimated equipment numbers, operational hours, and operating loads.

(b) The difference in estimated SO_2 emissions between market sectors "general industry" and "construction and mining" is most likely due to differences in market categorisation defined in ABARE when compared to categories used in this study.

There is good agreement between SO_2 emissions estimates based on ADO fuel consumption and the typical ADO sulfur content, and emission estimates developed during this study. Differences in SO_2 emission estimates between market sectors is most likely due to differences in market categorisation defined in ABARE when compared to categories used in this study.

3.4 Contribution of Non-road Diesel to Other Anthropogenic Emissions

Non-road diesel emission estimates are compared to on-road motor vehicle emissions (all fuels) in **Table 7**. The on-road motor vehicle emissions given in the table are drawn from the National Pollutant Inventory (NPI). In interpreting and using the NPI figures, reference should be made to NPI records which document the emission estimation methodologies applied and the uncertainties and limitations of methods and data inputs.

Table 7: Comparison of on-road motor vehicles (all fuels) to estimated in-service non-road diesel engine emissions

Sector	Source	Annual Emissions (tonnes per annum)		
		PM_{10}	VOC	NO_x
On-road motor vehicles(a)	NPI	12,000(c)	230,000	340,000
Non-road diesel engine/equipment emissions(b)	ENVIRON estimate	13,500	11,100	92,700

(a) Includes vehicles of all fuel types including both petrol and diesel vehicles.

(b) Includes emissions from lawn and garden, airport service, recreational, light commercial, industrial, construction, agricultural and logging equipment in addition to some commercial marine engines. Emissions from larger (greater than 37 kW) marine engines and all diesel locomotives were excluded due to their not being typically included in non-road diesel regulations abroad.

(c) It is noted that the emission estimate for on-road motor vehicles is for urban airsheds only and does not represent a national estimate for on-road engines.

SO_2 emissions were not compared due to the in-service non-road diesel engine emission estimates having been based on post January 2009 fuel sulfur content (10 ppm), whereas the fuel sulfur content for the NPI on-road vehicles estimates are in the range of 50 ppm to 500 ppm, depending on when the state emission inventories underpinning the NPI data were undertaken.

The NPI on-road vehicle emission estimates include emissions from both petrol and diesel powered vehicles. The on-road particulate emissions reported are primarily due to diesel-powered vehicles[(29)], with the gaseous releases representing contributions from both petrol and diesel vehicles.

PM_{10} emissions from non-road diesel engines are estimated to be of a similar magnitude as emissions from the on-road vehicles sector (**Table** 7). This is not unexpected given that these sectors consume similar volumes of ADO annually, with non-road diesel engines/equipment emitting higher amounts of PM per litre of fuel burned[(30)].

NO_x emissions from in-service non-road diesel engines/equipment are estimated to represent about 27% of the total NO_x emissions from on-road vehicles in urban airsheds. (**Table 7**).

3.5 Extrapolation of Non-road Diesel Emissions by State/Territory

Reference was made to 2007-8 ADO consumption data by state/territory to provide an estimation of the relative magnitude of non-road diesel emissions by state and territory. ADO Consumption Data by state/territory (excluding ABARE Division I – Transport &

29 Particulate emissions for diesel-driven, on-road passenger vehicles are greater than a factor of thirty higher than petrol-driven on-road passenger vehicles per equipment volume of fuel (Environment Australia, 2008).

30 DEWHA (2008). National Pollutant Inventory, Emission Estimation Technique Manual for Combustion Engines, Version 3.0, Australian Department of Environment, Water, Heritage and the Arts, June 2008.

Storage ADO consumption; herein termed the 'non-road' ADO consumption) are given in **Table 9**.

Table 8: ADO Consumption (excluding Road and Water Transport) by State/Territory (2007-8)								
	Units	NSW	Victoria	Queensland	Western Australia	South Australia	Tasmania	Northern Territory
Total 'Non-road' ADO Consumption (excluding Road and Water Transport)	ML	1,596	642	2,319	2,435	376	231	495
Percentage of Total 'Non-road' ADO Consumption (excluding Road and Water Transport)	%	19.7	7.9	28.6	30.1	4.6	2.8	6.1
% Non-road ADO Consumption by Market Sector								
	Units	NSW	Victoria	Queensland	Western Australia	South Australia	Tasmania	Northern Territory
Agriculture, forestry and fishing	%	39.0	51.2	21.6	12.4	53.1	33.7	4.7
Mining	%	39.9	18.1	45.0	46.8	9.7	25.8	47.1
Manufacturing	%	2.4	6.9	13.9	19.6	13.1	10.1	5.8
Electricity, gas and water	%	5.7	1.2	4.1	8.9	4.8	2.2	35.1
Construction	%	7.1	13.3	7.2	5.1	7.6	18.0	2.1
Commercial and services	%	5.7	8.5	7.7	6.9	10.3	10.1	4.7
Residential	%	0.2	0.8	0.6	0.2	1.4	0.0	0.5
Total	%	100	100	100	100	100	100	100

Source of ADO Consumption Data: ABARE, 2009[31].

Using 'non-road' ADO consumption figures by state/territory, and taking into account consumption by market sector within states/territories, national non-road diesel emissions estimated (**Section 3.3.1**) were apportioned by state and territory (**Table 9**). This method of approximating state/territory emissions is based on the assumption that the engine/equipment populations operating within specific market sectors are similar in terms of technology types, equipment age, power rating, operating hours (etc.) across all states and territories.

Table 9: Non-road Diesel Engine/Equipment Emissions by State/Territory (a)								
	Units	NSW	Victoria	Queensland	Western Australia	South Australia	Tasmania	Northern Territory
PM_{10}	tpa	2,960	1,166	3,939	3,751	616	395	691
VOC	tpa	2,377	945	3,238	3,115	510	320	588
NO_X	tpa	20,352	8,372	26,670	25,260	4,621	2,735	4,683

(a) Based on apportionment of estimated national non-road diesel emissions (Section 3.3.1) based on market sector specific 'non-road' ADO consumption rates within states/territories (Table 9).

31 ABARE (2009). Energy in Australia 2009, Australian Government Department of Resources, Energy and Tourism.

National non-road diesel related PM_{10} emissions (13.5 ktpa) were apportioned between states as follows: Queensland (29%), WA (28%), NSW (22%), Victoria (9%), South Australia (5%), Northern Territory (5%) and Tasmania (3%) (**Table 9**).

3.6 Case Study: Contribution of Non-road Diesel to NSW GMR Emissions

A summary of relevant non-road diesel engine/equipment emissions from the NSW Greater Metropolitan Region (GMR) Emissions Inventory (compiled for 2003) is given in **Table 10**(32).

Table 10: Summary of emissions from non-road diesel engine and equipment from the NSW GMR Emissions Inventory

Application	Annual Emissions (tonnes per annum)			
	PM_{10}	**Total VOCs**	**NO_x**	**$PM_{2.5}$**
Aircraft auxiliary power units and ground support equipment (airports)	11	189	318	10
Commercial boats < 50 kW	5	10	247	5
Commercial non-road vehicles and equipment(a)	83	77	821	80
Construction non-road vehicles and equipment(b)	14	16	196	14
Industrial non-road vehicles and equipment(c)	356	441	6,641	345
Lawn mowing and garden equipment (public open space)	27	285	59	25
Recreational boats < 37 kW	2	3	30	2
Stationary diesel engines and equipment	147	38	676	147
Total non-road diesel vehicles and equipment	**645**	**1,060**	**8,989**	**628**
Application	**Percentage Contribution to Total**			
	PM_{10}	**Total VOCs**	**NO_x**	**$PM_{2.5}$**
Aircraft auxiliary power units and ground support equipment (airports)	1.7	17.8	3.5	1.6
Commercial boats < 50 kW	0.8	0.9	2.7	0.8
Commercial non-road vehicles and equipment	12.9	7.3	9.1	12.7
Construction non-road vehicles and equipment	2.2	1.5	2.2	2.2
Industrial non-road vehicles and equipment	55.2	41.6	73.9	54.9
Lawn mowing and garden equipment (public open space)	4.2	26.9	0.7	4.0
Recreational boats < 37 kW	0.3	0.3	0.3	0.3
Stationary diesel engines and equipment	22.8	3.6	7.5	23.4

Source: DECC 2007, Air Emissions Inventory for the Greater Metropolitan Region in NSW, Department of Environment and Climate Change NSW, Sydney, NSW 2000, Australia.
http://www.environment.nsw.gov.au/air/airinventory.htm

(a) Commercial equipment includes aerial lifts, bulldozers, cranes, excavators, forklifts, loaders, off-highway trucks, other equipment, rubber tyre loaders, skid steer loaders, tractors, locaders and backhoes. Forklifts accounted for about 60% of inventoried commercial equipment, with off-highway trucks, tractors and loaders accounting for a further 30%. Aerial lifts and cranes comprised <2% of all equipment.

(b) Construction equipment includes concrete and industrial saws, cranes, crushing and processing equipment, excavators, forkliftes, graders, off-highway tractors and trucks, plate compactors, rollers, rubber tyre loaders, skid steer loades, tampers and rammers, tractors, loaders, backhoes and trenches. Excavators, rollers, compactors, loaders and tampers/rammers accounted for over 80% of inventoried equipment.

32 DECC 2007, Air Emissions Inventory for the Greater Metropolitan Region in NSW, Department of Environment and Climate Change NSW, Sydney, NSW 2000, Australia.

(c) Industrial equipment includes much of the same equipment as the Commercial and Construction equipment applications, with over 80% of industrial equipment inventoried as comprising forklifts, off-highway trucks, loaders, dozers, excavators and tractors.

In terms of contributions to total non-road diesel equipment PM emissions in the NSW GMR, the most significant applications are Industrial Non-road Vehicles and Equipment (55%), Stationary Diesel Engines and Equipment (23%) and Commercial Non-road Vehicles and Equipment (13%) (**Table 10**). The combined emissions from these three application types contribute 91% of the total non-road diesel engine/equipment emissions inventoried. Other applications which can broadly be classified as ‘industrial’, namely airport and construction equipment account for a further 4%.

Lawn mowing and garden equipment for public open space applications were found to contribute about 4% (**Table 10**).

Marine equipment, including commercial and recreational boats, were estimated to contribute only about 1% of PM emissions, when only small engines (typically regulated internationally under non-road diesel regulations) are taken into account (**Table 10**).

Non-road diesel emissions are compared to on-road diesel emissions for the NSW GMR in **Table 11**.

Table 11: Comparison of non-road and on-road diesel engine and equipment emissions for the NSW GMR

Application	Annual Emissions (tonnes per annum)			
	PM_{10}	Total VOCs	NO_x	$PM_{2.5}$
Total non-road diesel vehicles and equipment	645	1,060	8,989	628
Total on-road diesel vehicles	2,139	4,730	30,575	2,074
Total diesel vehicles and equipment	**2,784**	**5,790**	**39,564**	**2,703**
% Non-road Diesel	23	18	23	23

Source: DECC 2007, Air Emissions Inventory for the Greater Metropolitan Region in NSW, Department of Environment and Climate Change NSW, Sydney, NSW 2000, Australia. Information in Tables 10 and 11 is based on a survey in 2003. The new inventory underdevelopment will comprehensively characterize emissions from the non-road sector.

Diesel emissions within the NSW GMR, account for ~20% of total PM_{10}, $PM_{2.5}$, NO_x and VOC emissions.

3.7 Summary of Findings

The quantification of in-service non-road diesel engines/equipment is complicated by difficulties in accurately estimating the existing equipment population, and the diverse characteristics (age, emissions performance) and operations (operating hours, loads) of non-road equipment. Non-road diesel emission estimates therefore range significantly and are afforded a much lower degree of certainty than are on-road transport emission estimates.

PAE (2005) estimated the number of in-service non-road diesel engine/equipment numbers to be of the order of 550,000 based primarily on 2003 data[(33)]. Taking into account estimated non-road diesel engine and equipment sales figures for the 2003 to 2008 period (**Section 5.4**), and accounting for engine scrappage, it is expected that total in-service numbers would be in excess of 620,000 for 2008.

A revised estimation of in-service non-road diesel emissions was conducted during the current study based on the PAE (2005) inventoried population. Total PM and NO_x emissions were estimated to be 13.5 ktpa and 92.7 ktpa respectively. The revised in-service non-road diesel emission estimates are within the range considered feasible when national non-road ADO consumption is taken into account.

Based on market sector specific 'non-road' ADO consumption rates, the highest non-road diesel engine PM emissions were estimated to occur within Queensland (29%), Western Australia (28%) and NSW (22%), with emissions for other states/territories estimated to be in the range of 3% to 9%.

The most significant non-road diesel engine/equipment applications, in terms of both PM and NO_x emissions, were estimated to be Construction and Mining Equipment followed by Agricultural and Forestry Equipment. Construction and Mining Equipment was estimated to account for 61% of PM_{10} emissions and 56% of NO_x emissions estimated for the in-service non-road diesel population.

Nationally, PM_{10} emissions from non-road diesel engines are estimated to be of a similar magnitude as emissions from the the on-road vehicles sector. NO_x emissions from in-service non-road diesel engines/equipment are estimated to represent about 27% of the total NO_x emissions from on-road vehicles in urban airsheds.

33 PAE (2005). Management Options for Non-road Engine Emissions in Urban Areas, Report compiled by Pacific Air and Environment on behalf of the Department of the Environment and Heritage, November 2005.

4 Emission Standards for Non-road Diesel

An overview is given in this section of emissions standards promulgated by various countries and a brief comparison of these standards provided. The description of emission standards is provided ahead of the broader discussion of non-road diesel emission management in **Section 7**, in order to introduce the engine categorisation used in the characterisation of the Australian non-road diesel market presented in **Section 5**.

Factors taken into account in selecting the emissions standards to review included: countries from which engines are imported into Australia; widely referenced emission standards and regulatory regimes which are frequently referenced in Australia.

Based on these considerations, and taking into account the availability of emissions standards, the following standards were selected: US Federal, European Union (EU), China, Japan and India. Canadian standards reflect closely those promulgated in the US and are therefore omitted. Reference was made to the legislative overview provided by Ecopoint (2009) on the DieselNet website; particularly for regulations which could not be accessed in English(34).

The relevance of emission standards to the main Australian non-road engine sectors for the purpose of assessing their emission reduction performance is reviewed.

4.1 United States Emission Standards

US, non-road emission standards are based on engine horse-power and model year. US federal standards (Tier 1) were first implemented for new non-road diesel engines in 1994 for engines over 37 kW, to be phased-in from 1996 to 2000. In 1998 a regulation was passed introducing Tier 1 standards for equipment under 37 kW and increasingly more stringent Tier 2 and Tier 3 standards for all equipment with phased-in schedules from 2000 to 2008(35).

Tier 2 and Tier 3 standards are met through advanced engine design, with either no or only limited use of exhaust gas aftertreatment. Tier 3 standards for NO_x and hydrocarbons (HC) are similar in stringency to the 2004 standards for highway engines however the Tier 3 standards for PM were not adopted.

Tier 4 emission standards were introduced in 2004 as part of the US Clean Diesel Rule. This marked a shift towards the integration of engine and fuel control measures to further cost-optimise emission reductions from non-road diesel engines. Tier 4 emission standards are to be phased-in over the period 2008 to 2015. The initial set of Tier 4 emission standards, implementable from 2008 onwards, are termed Tier 4a, Tier 4 interim or Tier 4i standards. Tier 4 emission standards implementable from 2011 onwards are more stringent and are termed Tier 4b, Tier 4ii or Tier 4 final standards. Compliance with Tier 4 final standards require that emissions of PM and NO_x be further reduced by about 90%. Tier 4 final emission standards can be achieved through the use of control technologies, including

34 Ecopoint (2009). Summary of Worldwide Diesel Emission Standards, www.dieselnet.com/standards/, DieselNet.
35 US Code of Federal Regulations, Title 40, Part 89 *[40 CFR Part 89].*

advance exhaust gas aftertreatment similar to those required by the 2007-2010 standards for highway engines.

The sulfur content in non-road diesel fuels was not limited by environmental regulations during the Tier 1 to Tier 3 stages. At that time, the oil industry specification was 0.5% (maximum, by weight), with the average in-use sulfur level being in the range of 0.3% (3000 ppm). Tier 4 engines, which incorporate sulfur-sensitive control technologies such as catalytic particulate filters and NO_x adsorbers, necessitated the mandated reduction of sulfur content in non-road diesel fuels. The sulfur content was reduced to 500 ppm, effective June 2007, for non-road, locomotive and marine diesel fuels. The sulfur content will be further reduced to 15 ppm (ultra-low sulfur diesel) for non-road fuel (effective June 2010) and locomotive and marine fuels (effective June 2012).

4.1.1 Scope of Federal Non-road Emission Standards

Initially the US regulations including all non-road engines included all internal combustion engines, with the exception of motor vehicle (highway) engines, stationary engines, aircraft and engines used solely for competition.

In May 2003, the definition of non-road engines was changed to include all diesel powered engines – including stationary ones – used in agricultural operations in California. This change applied only to engines sold in the state of California, with stationary engines sold in other states not classified as non-road engines.

Non-road standards therefore generally cover mobile non-road diesel engines of all sizes used in a wide range of construction, agricultural and industrial equipment (and stationary engines in California).

Diesel engines not covered by US non-road engine emissions standards include:

- Railway locomotives, these being subject to separate EPA regulations[(36)].
- Engines used in marine vessels which are covered by separate EPA regulations[(37)]. Marine engines below 37 kW are subject to Tier 1-2 but not Tier 4 non-road emission standards. Certain marine engines that are exempt from marine standards may be subject to non-road regulations.
- Engines used in underground mining equipment. Diesel emissions and air quality in mines are regulated by the Mine Safety and Health Administration.

In US regulations, non-road engines are distinguished from highway engines in one of four ways:

(i) The engine is used in a piece of motive equipment that propels itself in addition to performing an auxiliary function (e.g. bulldozer grading a construction site);

36 40CFR Part 92
37 40CFR Part 94

(ii) The engine is used in a piece of equipment that is intended to be propelled as it performs its function;

(iii) The engine is used in a piece of equipment that is stationary but portable, such as a generator or compressor; or

(iv) The engine is used in a piece of motive equipment that propels itself, but is primarily used for non-road functions.

US Tier 1-3 emissions standards, expressed in grams of pollutant per kWh, are listed in **Table 12**. US Tier 4 emission standards are given in **Table 13** for engines up to 560 kW, and in **Table 14** for larger engines including generator sets greater than 900 kW.

The Tier 1 emission standards for nonmethane hydrocarbons (NMHCs) plus NO_x and PM standards, are approximately 15-50% lower than the uncontrolled levels.

Tier 1 to 2 emission standards reflected a 70% reduction in CO for greater than 130 kW engine sizes, a 30% reduction in NMHC and NO_x, and a 20% to 60% reduction in PM emissions. The shift from Tier 2 to 3 emission standards introduced a further 40% reduction in NMHC and NO_x emissions.

Tier 4 emissions standards make provision for the following reductions compared to Tier 1 levels:

- a 95% reduction in NO_x for engines less than 560 kW and 60% reduction for larger engines;
- a 85% reduction in HC for engines less than 560 kW and 70% reduction for larger engines; and
- a 50% to 60% reduction in PM during first phase (2008), and 80% to 95% reduction in second phase (2013-2015).

Tier 4 emission standards for CO remain unchanged from the Tier 2-3 standards.

As an alternative to introducing the required percentage of Tier 4 compliant engines, manufacturers in the US may certify all their engines to an alternative NO_x limit in each model year during the phase in period. Reference should be made to the rule for the alternative options.

US emission standards also make provisions for averaging, banking and trading of emission credits and maximum ‘family emission limits’ (FEL) for emission averaging.

US emission standards are applicable over the useful life of the engine. The US-EPA requires the application of deterioration factors to all engines covered by the rule. These factors are applied to the certification emission test data to represent emissions at the end of the useful life of the engine. The useful life is given as 5 years (3,000 hours) for all less than 19 kW and constant speed 19-37 kW engines (greater than 3000 rpm) and as 7 years (5,000 hours) for all other 19-37 kW engines. The useful life of engines greater than 37 kW is given as 10 years (8,000 hours). It should be noted that due to the nature of their design diesel engines are long lived and would be expected to be in operation beyond the above definition of 'useful life'.

Table 12: US-EPA Tier 1-3 Non-road Diesel Engine Emission Standards (g/kWh)

Engine Power	Tier	Year	CO	HC	NMHC+NOx	NOx	PM
kW < 8 (hp < 11)	Tier 1	2000	8	-	10.5	-	1
	Tier 2	2005	8	-	7.5	-	0.8
8 ≤ kW < 19 (11 ≤ hp < 25)	Tier 1	2000	6.6	-	9.5	-	0.8
	Tier 2	2005	6.6	-	7.5	-	0.8
19≤ kW < 37 (25 ≤ hp < 50)	Tier 1	1999	5.5	-	9.5	-	0.8
	Tier 2	2004	5.5	-	7.5	-	0.6
37 ≤ kW < 75 (50 ≤ hp < 100)	Tier 1	1998	-	-	-	9.2	-
	Tier 2	2004	5	-	7.5	-	0.4
	Tier 3	2008	5	-	4.7	-	(a)
75 ≤ kW < 130 (100 ≤ hp < 175)	Tier 1	1997	-	-	-	9.2	-
	Tier 2	2003	5	-	6.6	-	0.3
	Tier 3	2007	5	-	4	-	(a)
130 ≤ kW < 225 (175 ≤ hp < 300)	Tier 1	1996	11.4	1.3	-	9.2	0.54
	Tier 2	2003	3.5	-	6.6	-	0.2
	Tier 3	2006	3.5	-	4	-	(a)
225 ≤ kW < 450 (300 ≤ hp < 600)	Tier 1	1996	11.4	1.3	-	9.2	0.54
	Tier 2	2001	3.5	-	6.4	-	0.2
	Tier 3	2006	3.5	-	4	-	(a)
450 ≤ kW < 560 (600 ≤ hp < 750)	Tier 1	1996	11.4	1.3	-	9.2	0.54
	Tier 2	2002	3.5	-	6.4	-	0.2
	Tier 3	2006	3.5	-	4	-	(a)
kW ≥ 560 (hp ≥ 750)	Tier 1	2000	11.4	1.3	-	9.2	0.54
	Tier 2	2006	3.5	-	6.4	-	0.2

(a) Not adopted, engines must meet Tier 2 PM standard.

Table 13: US-EPA Tier 4 Emission Standards for engines up to 560 kW (g/kWh)*

Engine Power	Year	CO	NMHC	NMHC+NO_x	NO_x	PM
kW < 8 (hp < 11)	2008	8	-	7.5	-	0.4(a)
8 ≤ kW < 19 (11 ≤ hp < 25)	2008	6.6	-	7.5	-	0.4
19 ≤ kW < 37 (25 ≤ hp < 50)	2008	5.5	-	7.5	-	0.3
	2013	5.5	-	4.7	-	0.03
37 ≤ kW < 56 (50 ≤ hp < 75)	2008	5	-	4.7	-	0.3(b)
	2013	5	-	4.7	-	0.03
56 ≤ kW < 130 (75 ≤ hp < 175)	2012-2014(c)	5	0.19	-	0.4	0.02
130 ≤ kW ≤ 560 (175 ≤ hp ≤ 750)	2011-2014(d)	3.5	0.19	-	0.4	0.02

)* The initial set of Tier 4 emission standards, implementable from 2008 onwards, are termed Tier 4a or Tier 4i standards. Tier 4 emission standards implementable from 2011 onwards are more stringent and are termed Tier 4b, Tier 4ii or Tier 4 final standards.
(a) Hand-startable, air-cooled, DI engines may be certified to Tier 2 standards through 2009 and to an optional PM standard of 0.6 g/kWh starting in 2010
(b) 0.4 g/kWh (Tier 2) if manufacturer complies with the 0.03 g/kWh standard from 2012
(c) PM/CO: full compliance from 2012; NO_X/HC: Option 1 (if banked Tier 2 credits used)—50% engines must comply in 2012-2013; Option 2 (if no Tier 2 credits claimed)—25% engines must comply in 2012-2014, with full compliance from 2014.12.31
(d) PM/CO: full compliance from 2011; NO_X/HC: 50% engines must comply in 2011-2013

Table 14: US-EPA Tier 4 Emission Standards for Engines above 560 kW (g/kWh)

Year	Category	CO	NMHC	NO_x	PM
2011-2014	Generator sets > 900 kW	3.5	0.40	0.67	0.10
	All engines except gen sets > 900 kW	3.5	0.40	3.5	0.10
2015	Generator sets	3.5	0.19	0.67	0.03
	All engines except gen sets	3.5	0.19	3.5	0.04

4.2 European Union Emission Standards

Australia imports engines from various European countries including the United Kingdom, Germany, France, Sweden and Italy.

Non-road (off-road) mobile equipment regulations were first promulgated in the EU in 1997[38], with non-road diesel standards for new diesel engines introduced in two stages: Stage I implemented in 1999 and Stage II implemented from 2001 to 2004 (depending on the engine power output) (**Table 15**). Although this initial directive covered emissions from variable speed diesel engines in equipment such as excavators, dozers, loaders and backhoes, it was intended to be extended to almost all engines used for mobile applications which are not subject to vehicle approval requirements. This would represent an extension to include small mobile machinery such as garden equipment, generators and welders, construction machinery, industrial trucks, forklifts and mobile cranes.

Directive 2000/25/EU amended the 1997 Directive to include agricultural and forestry tractors, which were covered by the same emission standards but given different implementation dates.

Engines used in ships, railway locomotives, aircraft and generating sets are not covered by the EC Stage I and II standards.

Directive 2002/88/EC amended the 1997 Directive to further reduce diesel engines emission in general non-road application to reflect technological developments. This Directive also extended the scope of non-road engine regulation to include engines in inland waterway vessels, constant speed diesel engines, and imports of used engines. The utility engine emission standards incorporated are largely aligned with US emission standards for small utility engines.

Directive 2004/26/EC introduced Stage III and IV emission standards for non-road engines. Such standards were adopted for agricultural and forestry tractors in 2005 (2005/13/EC) (**Table 15**). Stage III standards are being phased-in from 2006 to 2013, with Stage IV standards entering into force in 2014. Stage III/IV standards include marine engines used for inland waterway vessels.

38 Directive 97/68/EC of the European Parliament and of the Council of 16 December 1997 on the approximation of the laws of the Member States relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery

Table 15: EU Emission Standards for Non-road Diesel Engines						
EU Stage I/II Emission Standards for Non-road Diesel Engines						
Cat.	**Net Power**	**Date***	**CO**	**HC**	**NO_x**	**PM**
	kW		g/kWh			
Stage I						
A	130 ≤ P ≤ 560	1999.01	5.0	1.3	9.2	0.54
B	75 ≤ P < 130	1999.01	5.0	1.3	9.2	0.70
C	37 ≤ P < 75	1999.04	6.5	1.3	9.2	0.85
Stage II(a)						
E	130 ≤ P ≤ 560	2002.01	3.5	1.0	6.0	0.2
F	75 ≤ P < 130	2003.01	5.0	1.0	6.0	0.3
G	37 ≤ P < 75	2004.01	5.0	1.3	7.0	0.4
D	18 ≤ P < 37	2001.01	5.5	1.5	8.0	0.8
(a)Stage II also applies to constant speed engines effective 2007.01						
Stage III A Standards for Non-road Engines						
Cat.	**Net Power**	**Date(b)**	**CO**	**NO_x+HC**		**PM**
	kW		g/kWh			
H	130 ≤ P ≤ 560	2006.01	3.5	4.0		0.2
I	75 ≤ P < 130	2007.01	5.0	4.0		0.3
J	37 ≤ P < 75	2008.01	5.0	4.7		0.4
K	19 ≤ P < 37	2007.01	5.5	7.5		0.6
(b)dates for constant speed engines are: 2011.01 for categories H, I and K; 2012.01 for category J.						
Stage III B Standards for Non-road Engines						
Cat.	**Net Power**	**Date**	**CO**	**HC**	**NO_x**	**PM**
	kW		g/kWh			
L	130 ≤ P ≤ 560	2011.01	3.5	0.19	2.0	0.025
M	75 ≤ P < 130	2012.01	5.0	0.19	3.3	0.025
N	56 ≤ P < 75	2012.01	5.0	0.19	3.3	0.025
P	37 ≤ P < 56	2013.01	5.0	4.7(c)		0.025
(c) NO_x+HC						
Stage IV Standards for Non-road Engines						
Cat.	**Net Power**	**Date**	**CO**	**HC**	**NO_x**	**PM**
	kW		g/kWh			
Q	130 ≤ P ≤ 560	2014.01	3.5	0.19	0.4	0.025
R	56 ≤ P < 130	2014.10	5.0	0.19	0.4	0.025
Stage III A Standards for Inland Waterway Vessels						
Cat.	**Displacement (D)**	**Date**	**CO**	**NO_x+HC**		**PM**
	dm^3 per cylinder		g/kWh			
V1:1	D ≤ 0.9, P > 37 kW	2007.01	5.0	7.5		0.40
V1:2	0.9 < D ≤ 1.2		5.0	7.2		0.30
V1:3	1.2 < D ≤ 2.5		5.0	7.2		0.20
V1:4	2.5 < D ≤ 5	2009.01	5.0	7.2		0.20
V2:1	5 < D ≤ 15		5.0	7.8		0.27
V2:2	15 < D ≤ 20, P ≤ 3300 kW		5.0	8.7		0.50
V2:3	15 < D ≤ 20, P > 3300 kW		5.0	9.8		0.50
V2:4	20 < D ≤ 25		5.0	9.8		0.50
V2:5	25 < D ≤ 30		5.0	11.0		0.50

Inland waterway vessels subject to EU Stage III/IV emission standards are defined as vessels intended for use on inland waterways having a length of 20 metres or more and having a volume of 100 m^3 or more, or tugs or pusher craft having been built to tow or to push or move alongside vessels of 20 metres or more. The EU definition does not include: vessels intended for passenger transport carrying less than 12 people (including crew); recreational craft with a length of less than 24 metres; service craft belonging to supervisory authorities; fire-service vessels; naval vessels; fishing vessels on the register of the EU; and sea-going vessels.

Stage III and IV emission standards apply only to new engines. Replacement engines to be used in machinery already in use (except for some large engines such as inland waterway vessel propulsion engines) are required to comply with the standards which were in place when the engine to be replaced was placed on the market.

Stage III B standards introduce PM limit of 0.025 g/kWh, representing about a 90% emission reduction relative to Stage II. To meet this limit value, it is anticipated that engines will have to be equipped with particulate filters. Stage IV also introduces a very stringent NO_x limit of 0.4 g/kWh, which is expected to require NO_x aftertreatment.

To determine compliance with EU emission standards, emissions have to date been measured on the ISO 8178 C1 8-mode cycle (termed the Non-road Steady Cycle, NRSC) and expressed in g/kWh. Stage I and II engines are tested using fuel of 0.1-0.2% (wt.) sulfur content.

A new transient test procedure, termed the Non-road Transient Cycle (NRTC), was developed in cooperation with the US-EPA to represent emissions during real conditions. NRTC is to be used in parallel with NRSC.

4.3 Emission Standards for Japan

Japan issues emission standards for non-road vehicles and machinery rated between 19-560 kW, including *Special Motor Vehicles* (self-propelled non-road vehicles and machinery that are registered for operation on public roads, i.e. fitted with licence plates) and *Non-road Motor Vehicles* that are self-propelled and non-registered non-road vehicles and machinery[(39)]. The emission standards for the two vehicle categories are the same, despite their being introduced by separate regulatory acts. The emission standards published for compression ignition engines are given in **Table 16**.

The Japanese emission standards, despite being similar in stringency to the US Tier 3 (2006-8) and the EU Stage III A (2005-2007), are not harmonized with US and EU regulations. The standards do not require the use of exhaust aftertreatment devices, such as diesel particulate filters. The Japanese Ministry of the Environment's Central Environmental Council are however considering adopting aftertreatment forcing standards with implementation dates around 2010.

39 Ministry of Environment (MOE) Government of Japan, Enforcement Regulations for the Act on Regulation of Emissions from Non-road Special Motor Vehicle (http://www.env.go.jp/).

Table 16: Emission Standards for Diesel Special/Non-road Vehicles by Japan (g/kWh)							
Power (P)	CO	HC	NOx	PM	Smoke	Date	
						New Models	All Models(a)
kW	g/kWh				%		
19 ≤ P < 37	5.0	1.0	6.0	0.4	40	2007.10	2008.09
37 ≤ P < 56	5.0	0.7	4.0	0.3	35	2008.10	2009.09
56 ≤ P < 75	5.0	0.7	4.0	0.25	30	2008.10	2010.09
75 ≤ P < 130	5.0	0.4	3.6	0.2	25	2007.10	2008.09
130 ≤ P < 560	3.5	0.4	3.6	0.17	25	2006.10	2008.09

(a) Applies to continuously produced non-road vehicles (but not special vehicles) and imported special/non-road vehicles.

4.4 Emission Standards for China

China adopted emission standards for mobile non-road engines in 2008[40] (**Table 17**). Compliance dates are given as October 2007 for Stage I and October 2009 for Stage II.

Table 17: China - Emission Standards for Non-road Diesel Engines (g/kWh)					
Max Power (P), kW	**CO**	**HC**	**NOx**	**HC+NOx**	**PM**
Stage I(a)					
130 ≤ P ≤ 560	5.0	1.3	9.2	-	0.54
75 ≤ P < 130	5.0	1.3	9.2	-	0.7
37 ≤ P < 75	6.5	1.3	9.2	-	0.85
18 ≤ P < 37	8.4	2.1	10.8	-	1.0
8 ≤ P < 18	8.4	-	-	12.9	-
0 < P < 8	12.3	-	-	18.4	-
Stage II					
130 ≤ P ≤ 560	3.5	1.0	6.0	-	0.2
75 ≤ P < 130	5.0	1.0	6.0	-	0.3
37 ≤ P < 75	5.0	1.3	7.0	-	0.4
18 ≤ P < 37	5.5	1.5	8.0	-	0.8
8 ≤ P < 18	6.6	-	-	9.5	0.8
0 < P < 8	8.0	-	-	10.5	1.0
(a) Stage I limits shall be achieved before any exhaust aftertreatment device.					

The standards promulgated by China are based on the EU Stage I/II emission standards for mobile non-road engines, but also cover small diesel engines were which not subject to EU standards. Emission limits for the smallest engines are consistent with US Tier1/2 non-road diesel standards.

40 Regulation GB 20891-2007.

4.5 Emission Standards for India

Emission standards for diesel construction machinery and agricultural tractors have been introduced by India[41](**Table 18**).

Table 18: India – Emission Standards for Diesel Construction Machinery and Agricultural Tractors

Bharat (CEV) Emission Standards for Diesel Construction Machinery						
Engine Power	Date	CO	HC	$HC+NO_x$	NO_x	PM
kW		g/kWh				
Bharat (CEV) Stage II						
P < 8	2008.10	8.0	1.3	-	9.2	1.00
8 ≤ P < 19	2008.10	6.6	1.3	-	9.2	0.85
19 ≤ P < 37	2007.10	6.5	1.3	-	9.2	0.85
37 ≤ P < 75	2007.10	6.5	1.3	-	9.2	0.85
75 ≤ P < 130	2007.10	5.0	1.3	-	9.2	0.70
130 ≤ P < 560	2007.10	5.0	1.3	-	9.2	0.54
Bharat (CEV) Stage III						
P < 8	2011.04	8.0	-	7.5	-	0.80
8 ≤ P < 19	2011.04	6.6	-	7.5	-	0.80
19 ≤ P < 37	2011.04	5.5	-	7.5	-	0.60
37 ≤ P < 75	2011.04	5.0	-	4.7	-	0.40
75 ≤ P < 130	2011.04	5.0	-	4.0	-	0.30
130 ≤ P < 560	2011.04	3.5	-	4.0	-	0.20
Bharat (Trem) Emission Standards for Diesel Agricultural Tractors						
Engine Power	Date	CO	HC	$HC+NO_x$	NO_x	PM
kW		g/kWh				
Bharat (Trem) Stage I						
All	1999.10	14.0	3.5	-	18.0	-
Bharat (Trem) Stage II						
All	2003.06	9.0	-	15.0	-	1.00
Bharat (Trem) Stage III						
All	2005.10	5.5	-	9.5	-	0.80
Bharat (Trem) Stage III A						
P < 8	2010.04	5.5	-	8.5	-	0.80
8 ≤ P < 19	2010.04	5.5	-	8.5	-	0.80
19 ≤ P < 37	2010.04	5.5	-	7.5	-	0.60
37 ≤ P < 75	2011.04	5.0	-	4.7	-	0.40
75 ≤ P < 130	2011.04	5.0	-	4.0	-	0.30
130 ≤ P < 560	2011.04	3.5	-	4.0	-	0.20

The diesel construction machinery standards, introduced in 2006, are structured into two tiers: (i) Bharat (CEV) Stage II standards being based on EU Stage I standards but also covering smaller engines not regulated under EU Stage I, and (ii) Bharat (CEV) Stage III which are based on the US Tier 2/3 standards. In addition to the emission standards for

41 Ecopoint (2009). Summary of Worldwide Diesel Emission Standards, www.dieselnet.com/standards/, DieselNet.

construction machinery, India has also previously promulgated standards for diesel agricultural tractors, for implementation in three stages, during the 1999-2005 period.

4.6 Applicability of International Standards for Australia

The applicability of the scope of US and EU non-road diesel engine emission standards to inventoried loose diesel engines inventoried for Australia is illustrated in **Figure 3** and **Figure 4** respectively[42]. It should be noted that the power rating bands for which loose diesel engine sales are reported do not align exactly with the power ratings for which the US and EU regulations are specified, the applicability of such regulations is therefore given as approximate.

It is estimated that the US non-road diesel engine emission standards are applicable to over 95% of the inventoried loose diesel engines, whereas the EU non-road mobile equipment emission standards are applicable to less than 30% of the inventoried loose diesel engines.

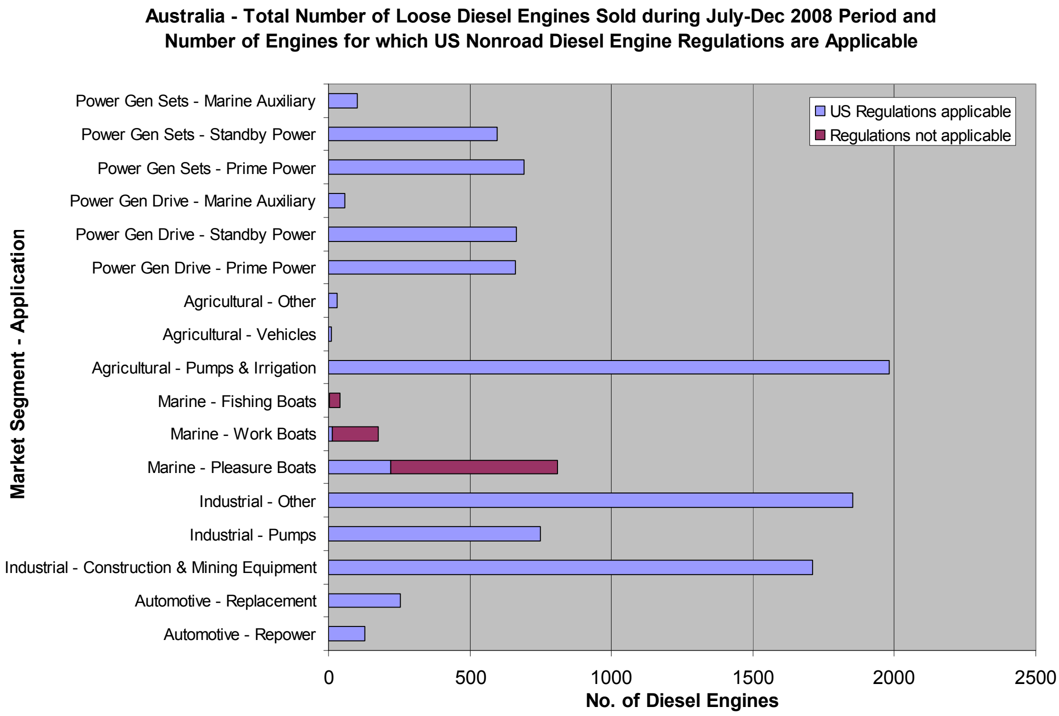

Figure 3: Total number of loose diesel engines sold in Australia from July to December 2008 and estimated number of engines for which US non-road diesel emission standards are applicable

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42 Loose engines are the single largest non-road engine emission category. The assessment Included the market applications and power ratings of the engines sold during the July to December 2008 period.

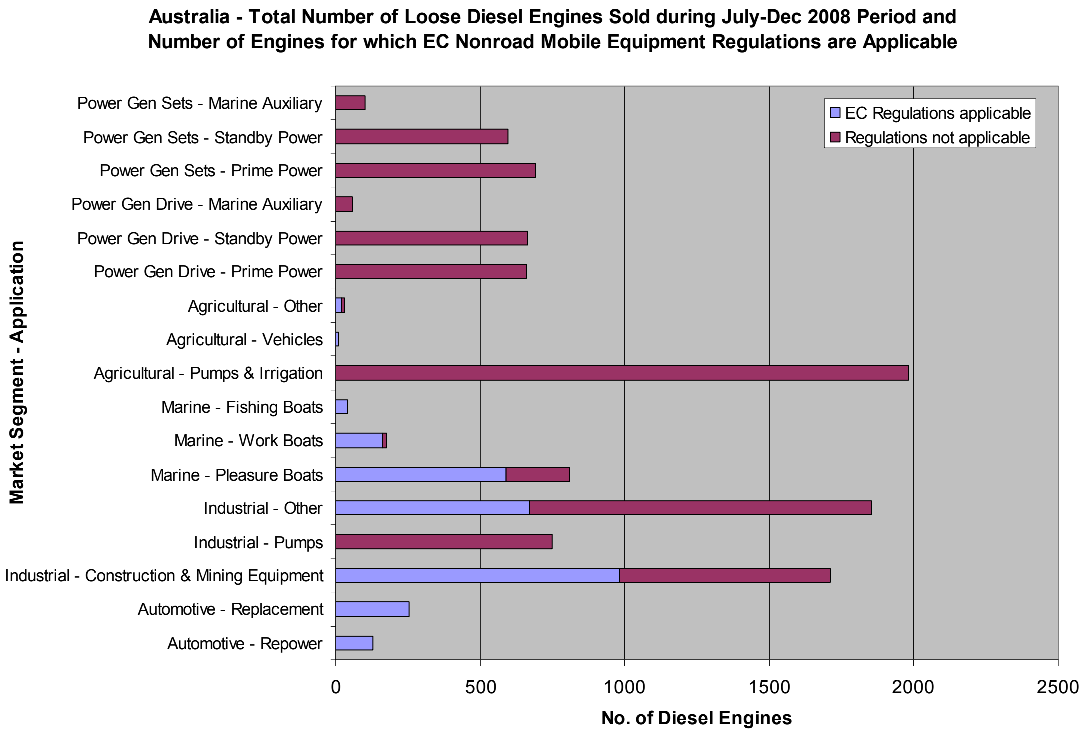

Figure 4: Total number of loose diesel engines sold in Australia from July to December 2008 and estimated number of engines for which EU non-road mobile equipment emission standards are applicable

4.7 International Trends in Emission Standards and Applicability to Australia

4.7.1 International Trends in Emission Standards

The US and EU emission standards are the most widely referenced and applied emission standards for non-road diesel engines. Canadian standards closely relect US emission limits. The main trends for international standards have been for increasing stringency, improved harmonization and more extensive coverage. A comparison of EU and US emission standards for PM is given in **Figure 5**. It is evident that these emission standards have become increasingly aligned in terms of the limit values promulgated. There has also been increasing cooperation in the development of test methods for evaluating the compliance of engines.

EU Stage III/IV and US 4 emission standards require significant reduction in PM and NO_x (~90% reductions). Such emission standards are only achievable through the use of control technologies, and can therefore be termed "aftertreatment forcing". In some instances advanced exhaust gas aftertreatment similar to that implemented for highway engines is required. The incorporation of sulfur-sensitive control technologies such as catalytic particulate filters and NO_x adsorbers in engines has also necessitated reductions of sulfur content in non-road diesel fuels.

Key differences between the US and EU emission standards include the engine classes and applications covered, notably:

- US emission standards have wider coverage including small engines (less than 8 kW) and large engines (greater than 560 kW) including generation sets of greater than 900 kW. EU emissions standards are generally only applicable to engines greater than 18 kW and less than 560 kW.

- Although both US and EU non-road diesel emission standards include certain marine engines, the manner in which these engines are defined differs significantly. The US primarily bases its definition on engine size, with marine engines smaller than 37 kW being subject to non-road diesel emission standards. The EU definition for inland waterway vessels is complex, with a number of exclusions. Detailed information on vessel sizes and applications is required in order to determine whether the EU non-road diesel engine emission standards are applicable.

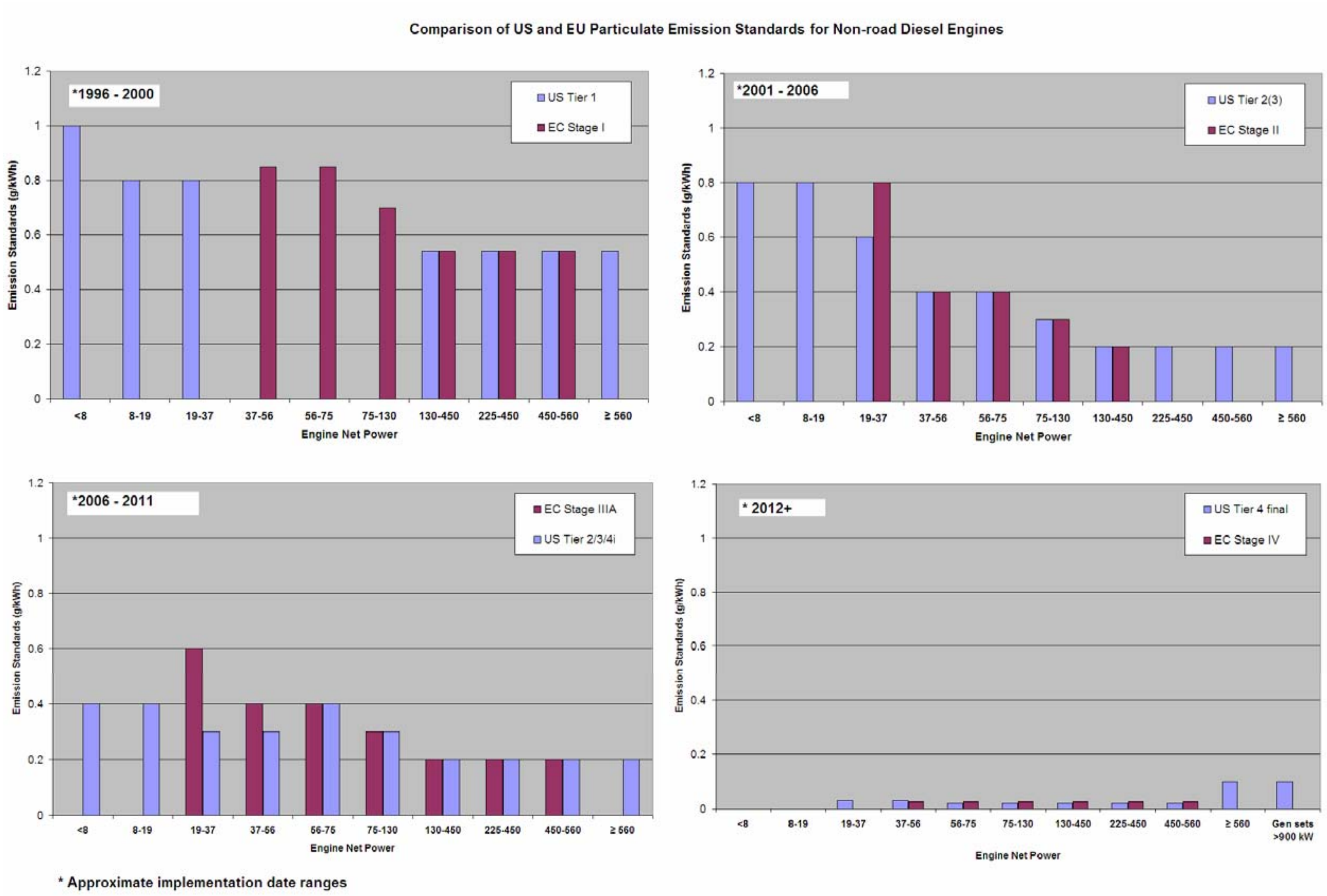

Figure 5: Comparison of US and EU emission standards for non-road diesel engines (particulate matter)

Non-road diesel engine emissions standards published for particulate matter by the US, EC, Japan, China and India (excluding standards applicable post 2010) are compared in **Figure 6**. Whereas the non-road diesel emissions standards published by Japan are more in line with the Stage IIIA and US Tier 4i PM emission standards, emission standards applied in China and India are lagging and more indicative of EU Stage I/II and US Tier 1/2 emission standards.

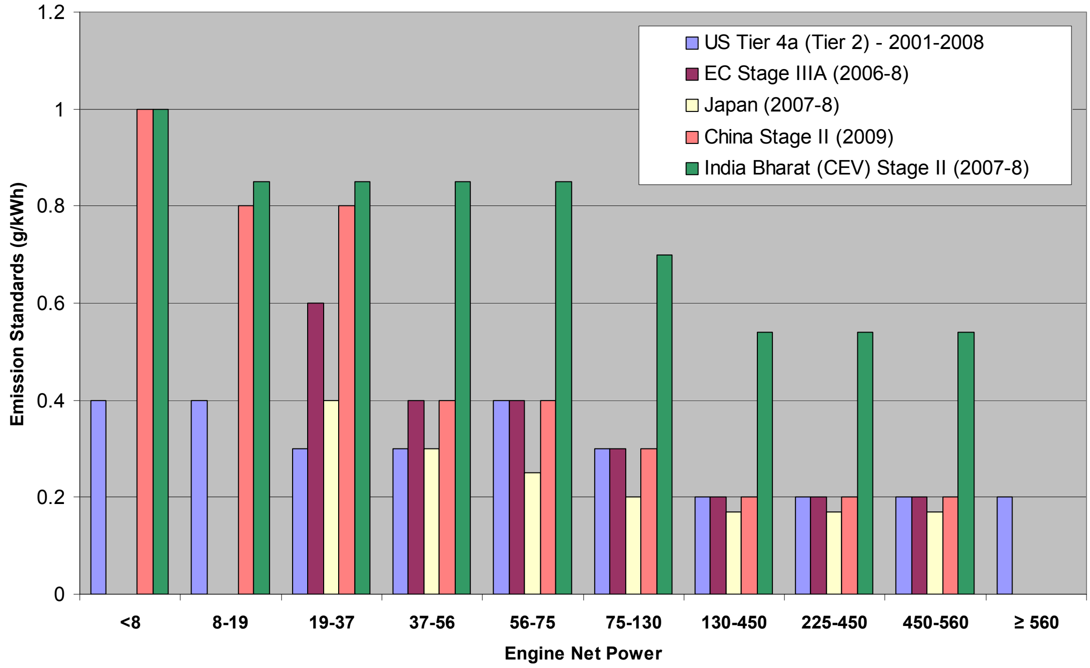

Figure 6: Comparison of particulate matter emission standards for non-road diesel engines published by the US, EC, Japan, China and India for implementation prior to 2010.

China and India have based their non-road emission standards primarily on the EU Stage I/II emission standards for mobile non-road engines. It is however notable that both countries have extended the coverage of such standards to make provision for small diesel engines which are not covered in terms of the EU standards. In setting emission limits for the smallest engines, reference is made to the US Tier 1/2 non-road diesel standards.

Japan's non-road diesel emission standards are similar to but not equivalent to (or harmonized with) US Tier 3 (2006-8) and the EU Stage III A (2005-2007) standards. It is notable that Japan has not issued emission standards for smaller engines, as in the case of the US, China and India. Although Japan has not yet adopted additional non-road diesel engine standards, there is pressure for more harmonization with EU and US emission standards and expectations that such regulations will be "aftertreatment forcing".

4.7.2 Summary of applicability of International Emission Standards

As indicated, US and EU non-road diesel engine emission standards are the most widely referenced and applied emission standards for non-road diesel engines. These standards are considered trend setting, with various countries incorporating components of one or both of these regulatory frameworks into their non-road diesel engine regulations. Such countries however tend to lag in terms of the stringency of the emission limits adopted.

A preliminary assessment of the coverage provided by the US and EU non-road diesel engine regulations was undertaken, taking into account loose diesel engine sales inventoried for Australia during 2008. Based on this assessment, US regulations are concluded to provide the broadest coverage in terms of the number of engines to which emission standards are applicable. This is primarily due to provision being made for the smallest engines within US non-road diesel engine regulation. It is pertinent to consider the coverage of US and EU non-road diesel engines in terms of the percentage coverage of total emissions from non-road diesel engine/equipment used in Australia.

5 Australian Non-road Diesel Industry

This section characterizes the Australian non-road diesel engine and equipment industry based on previous studies[43][44][45] and on information and product data collated from industry during the course of the study. An overview is provided of the size and diversity of the market in terms of engine imports and sales, market segmentation, equipment types and their application, and numbers of brands being marketed.

Engine/equipment compliance with international emission standards is assessed based on emission performance information collated during the study, and an indication provided of sectors likely to be price sensitive.

5.1 Industry Structure, Segmentation and Key Industry Associations

5.1.1 Industry Structure, Size and Segmentation

Diesel engines are not manufactured locally but rather imported into Australia, either as loose diesel engines or already incorporated into equipment. Key industry players, in terms of understanding new diesel engines entering Australia, therefore include companies supplying loose diesel engines[46] and companies importing equipment and machinery which have diesel engines. Most loose diesel engines are sold to various local equipment manufacturers over which the original engine supplier has no control. Although some local equipment suppliers import equipment with engines already in place, some Original Equipment Manufacturers (OEM) in Australia import engines directly from overseas manufacturers, thus bypassing traditional distributor channels in Australia.

The main market segments for the Australian non-road diesel industry reflect the applications of diesel engines/equipment and include: Agriculture, Construction and Mining, General Industrial, Power Generation, Light Commercial (pumps and compressors), Airport Service Equipment, Logging, Commercial Marine and Commercial Lawn and Garden equipment. An overview of such applications was provided in **Section 2.2**.

Over 50 brands of diesel engines are imported for sale in Australia. Although many of these brands have one main Australian representative, a few brands are supplied locally by a number of diverse state dealers. In most cases, engine and equipment sales within individual market segments is dominated by a small number of leading brands with the remaining small proportion of the market being shared by a wide range of alternative brands. More information on the number of dominant brands is provided in subsequent sections.

A review of industry associations indicates that industry players have organised themselves into three main groupings, namely: ‘loose’ diesel engine suppliers, ‘construction and mining’

43 PAE (2005). Management Options for Non-road Engine Emissions in Urban Areas, Report compiled by Pacific Air and Environment on behalf of the Department of the Environment and Heritage, November 2005.
44 NSW DECCW (2007). Air Emissions Inventory for the Greater Metropolitan Region in New South Wales, New South Wales, Department of Environment, Climate Change and Water, Sydney.
45 PAE (2003). Non-road Engine Emissions Invenotry Source Contribution Review, Report undertaken for the Australian Government Department of the Environment and Heritage, 13 February 2007.
46 Loose diesel engines refer to engines sold for use in new equipment or as replacement engines for in-service equipment.

equipment suppliers, and agricultural ('tractor and machinery') equipment suppliers. It is notable that the so-called 'construction and mining' equipment types supplied have wider applications which include industrial, commercial and forestry uses.

5.1.2 Industry Associations

The most pertinent industry associations are the recently constituted Australian Diesel Engine Distributors Association (ADEDA); the Construction and Mining Equipment Industry Group (CMEIG); and the Tractor and Machinery Association of Australia (TMA).

ADEDA was formed by a number of loose diesel engine distributors and it is estimated that its members represent over 70**%** of total sales for this sector. CMEIG is a non-profit organisation representing the construction and mining equipment industry and allied equipment and services on issues impacting on the delivery of business. CMEIG members represent over 80**%** of annual sales in this sector. The TMA is a member based industry organisation representing the interests of manufacturers, distributors, importers, dealers and other companies active in the Australian agricultural mechanisation industry. TMA sales data are expected to represent over 90% of the total market.

Other associations identified include: Heavy Engineering Manufacturers' Association, Australian Construction Industry Forum (ACIF), Airport Industries Australia, Australian Marine Industry Federation, Association of Mining and Exploration Companies (AMEC), Association of Australasian Diesel Specialists (AADS), Farm and Industrial Machinery Dealers Association of Australia. These associations were however not found to be significant sources of pertinent information.

Potentially significant engine and equipment manufacturers/distributors/suppliers were identified based on industry association memberships, web-based searches of popular brands and Australian representatives of such brands, and on market data obtained from the Equipment Research Group Pty Ltd (ERG International). ERG International is a market research company which collates data directly from industry suppliers including suppliers of non-road diesel engines and equipment. ERG International is affiliated to ADEDA and CMEIG.

5.2 Product (Import, Export, Sales) Data Availability

Four primary data sets were identified as being of relevance in characterizing the non-road diesel engine/equipment sold in Australia:

- Non-road diesel engine and equipment import and export data collected by the Australian Bureau of Statistics (ABS). Relevant data are spread across a range of customs tariff classifications, and are available as number of units imported by country of origin.

- Loose diesel engine sales data collated by ERG International, which currently liaises closely with the newly formed Australian Diesel Engine Distributors Association (ADEDA).

- Construction and mining equipment sales data (including certain industrial and commercial equipment types) collated by ERG International under the auspices of the Construction and Mining Equipment Industry Group (CMEIG).
- Agricultural equipment sales data collected by the Tractor and Machinery Association of Australia (TMA).

Apart from import statistics available from the ABS, there is no published or publicly available information on the Australian diesel engine market. It was therefore necessary to purchase loose diesel engine and construction and mining equipment market information from ERG International to aid in the characterisation of the market and direct further data collation. Market data were made available by the TMA for the agricultural sector.

The import and sales data sets do not include any information relating to the emission performance of engines and equipment. Major engine and equipment suppliers were therefore individually surveyed to obtain the required emission performance information.

5.3 Diesel Engine and Equipment Imports

Using customs data an estimate for non-road diesel engines and equipment imported into the Australian market has been developed. However, there are some limitations to this data. The Customs tariff code system used by the ABS for the classification and management of product import information does not readily lend itself to the accurate extraction of statistics for non-road diesel engines and equipment sold into the Australian market. The import numbers include a broad range of equipment types, including equipment using fuel types other than diesel and even, in certain instances, manual machinery.

Tariff code classifications identified as being of possible relevance, in terms of including or potentially/partially including non-road diesel engines/equipment are listed in **Table 19**. Total numbers of equipment types imported into Australia during 2008 for these equipment categories are given, and an estimate provided of the likely number of non-road diesel engines/equipment imported, with the basis for the estimation indicated.

Certain of the customs tariff categories are too broad to allow the estimation of potential non-road diesel equipment numbers. Such categories include both manual and fuel-powered equipment and range across fuel types with the number of diesel equipment imports anticipated to be a very small portion of the total equipment numbers reported. Diesel-powered compressors, pressure washers and welders could not be estimated due to this limitation. Based on the in-service population of diesel-powered equipment estimates of PAE (2005) [47], it is expected that the annual sales of these equipment will be of the order of 1,000 (comprising of about 84% welders, 13% air compressors and 3% pressure washers).

47 PAE (2005). Management Options for Non-road Engine Emissions in Urban Areas, Report compiled by Pacific Air and Environment on behalf of the Department of the Environment and Heritage, November 2005.

Table 19: Approximation of non-road numbers of equipment types imported into Australia during 2008. (This refers to equipment categories which (potentially) include non-road diesel engines/equipment).

Market Segment	Equipment Type (Custom's Tariff Code System)	Equipment Numbers Imported (2008) - ABS	Estimated 'Non-road Diesel' Imports (Approximation)	Basis for Estimation
Agricultural	Agricultural tractors	19,035	19,000	Estimated by PAE, 2005 to be 99.8% diesel for existing population
Agricultural	Combine harvester-threshers	509	500	Estimated by PAE, 2005 to be 99.2% diesel for existing population
Marine	Marine compression-ignition engines	4,538	1,000	According to 2008 Sales data only 23% of Marine Engines are in the less than 37 kW range(b)
Broad Industrial(a)	Potential off-road vehicle diesel engines	1,479	1,500	
Various	'Other' compression-ignition diesel and semi-diesel engines (excluding marine engines and gensets)	10,453	10,500	
Various	Diesel generation sets	16,638	16,600	
Broad Industrial(a)	Self-propelled track laying bulldozers and angle dozers	933	900	Estimated by PAE, 2005 to be 100% diesel for existing population
Broad Industrial(a)	Self-propelled bulldozers and angle dozers	109	100	Estimated by PAE, 2005 to be 100% diesel for existing population
Broad Industrial(a)	Self-propelled graders & levellers	877	900	Estimated by PAE, 2005 to be 100% diesel for existing population
Broad Industrial(a)	Self-propelled scrapers	138	150	Estimated by PAE, 2005 to be 100% diesel for existing population
Broad Industrial(a)	Self-propelled tamping machines and road rollers	1,653	900	Estimated by PAE, 2005 to be 55% diesel for existing population
Broad Industrial(a)	Self-propelled front-end shovel loaders	5,746	5700	Estimated by PAE, 2005 to be 99% diesel for existing population
Broad Industrial(a)	Mechanical shovels, excavators & shovel loaders	5,019	5,000	Estimated by PAE, 2005 to be about 100% diesel for existing population
Broad Industrial(a)	Other self propelled machinery for handling earth, minerals or ores	2,797	2,300	Estimated by PAE, 2005 to be 83% diesel for existing population
Broad Industrial(a)	Scrapers for earth, minerals or ores	201	200	Estimated by PAE, 2005 to be 100% diesel for existing population
Broad Industrial(a)	Off-highway dumpers	1,725	1,700	Estimated by PAE, 2005 to be 100% diesel for existing population
Broad Industrial(a)	Tractors (expected to include airport equipment)	562	550	Estimated by PAE, 2005 to be 100% diesel for existing population
Broad Industrial(a)	Forklifts	12,187	600	PAE, 2005 (50% of forklifts are internal combustion engines, of which 10% are diesel - PAE indicates only 12,000 forklifts sold in total - implying 600 diesel forklifts)
Broad Industrial(a)	Cranes and lifting equipment	9,503	2,900	PAE, 2005 (30% of aerial lifts estimated to be diesel)
Lawn and Garden	Ride on or tractor lawn mower	53,120	1,900	PAE 2005 (3.5% diesel); Confirmed based on OPEA sales information for 2005-6 which indicates that 51,000 petrol mowers were sold
Light Commercial	Welders, air compressors and pressure washers	ND	1,000	Diesel-powered compressors, pressure washers and welders could not be estimated from the broad Customs tariff classification. Based on the in-service population of diesel-powered equipment estimates of PAE (2005), it is expected that the annual sales of these equipment will be of the order of 1,000 (comprising of about 84% welders, 13% air compressors and 3% pressure washers).
	TOTAL		73,900	

(a) 'Broad Industrial' in this context includes industrial, commercial, construction, mining and airport applications.
(b) Only marine engines smaller than 37 kW were included in this study, given that such engines are covered specifically by US non-road diesel emission standards. (The US regulate marine diesel engines above 37 kW under marine specific US-EPA rulemakings.)

Based on the ABS import statistics it is estimated that 73,900 non-road diesel engines/equipment are imported into Australia on an annual basis. To assess whether the available sales data sets are likely to cover imports, the approximated compression-ignition import numbers were classified as follows:

Classification of Import Data for the Purpose of Assessing Sales Data Completeness	Major Sales Data Sets Available
Agricultural equipment (primarily tractors) (26% of imports)	Tractor sales supplied by TMA
Loose engines and generator sets (40% of imports)	Loose diesel engines sales supplied by ERG International with permission from ADEDA
Heavy Construction, Mining, Industrial and Commercial equipment (e.g. loaders, rollers, dumpers) (24% of imports)	Construction and Mining equipment sales supplied by ERG International with permission from CMEIG
Remaining 10% of imports included: Other industrial equipment (airport GSE, lifting, forklifts); light commercial equipment (compressors, welders, pressure washers) and ride on and tractor lawn mowers	Sales data to be derived from historical sales as referenced in subsequent sections

The ERG International and TMA sales data sets combined are expected to cover about 70% to 90% of estimated non-road diesel engine/equipment imports.

5.3.1 Countries of Origin

Imports are reported from over 60 different countries of origin for the equipment categories of interest. The percentage of imports by country of origin for the most significant equipment categories is given in **Table 20**.

Japan accounts for over 40% of self-propelled construction equipment, over 30% of compression-ignition engines and almost 20% of agricultural tractors. The US accounts for about 25% of all diesel engines, self-propelled construction and mining equipment and tractors. China is a significant source of cranes and lifting equipment, accounting for about 70% of such imports, and also contributing 12% of diesel engines imports. Japan, the US and China are the largest sources, together accounting for 67% of total imports across these equipment categories. Germany, Italy, the UK, Korea, Sweden, France and India represent more minor sources of total imports.

Table 20: Country of origin of equipment categories comprising significant numbers of non-road diesel engine/equipment
(This excludes light commercial equipment such as generators, pumps and compressors)

Country of Origin	Percentage of Imports within Equipment Category					Percentage of Total Imports
	Agricultural Tractor	Compression-ignition engines (diesel or semi-diesel engines)	Self-propelled construction and mining equipment	Ships' derricks, cranes, etc.	Tractor (other than agricultural tractors)	
Japan	19.28	32.61	43.66	2.27	1.10	27.30
United States of America	28.75	24.50	24.26	1.33	26.65	21.87
China	4.91	12.03	5.79	69.48	7.71	18.02
Germany	11.07	5.78	2.56	1.24	63.22	5.84
Italy	7.76	4.96	0.00	13.16	0.88	5.83
United Kingdom	1.95	6.79	2.59	1.54	0.22	4.28
Korea, Republic of	6.67	0.95	5.15	0.15	0.00	2.71
Sweden	0.01	3.83	1.72	1.98	0.00	2.41
France	2.87	1.75	1.87	0.40	0.00	1.78
India	5.97	0.21	0.00	0.45	0.00	1.35
Thailand	0.00	1.86	0.26	0.00	0.00	0.92
Indonesia	0.00	1.92	0.03	0.00	0.00	0.91
Austria	3.10	0.11	0.13	0.96	0.00	0.83
Netherlands	0.02	0.40	0.25	3.33	0.00	0.73
Viet Nam	3.09	0.02	0.29	0.01	0.22	0.67
No Country Details	0.00	0.00	3.74	0.00	0.00	0.67
Canada	2.12	0.12	0.31	0.12	0.00	0.55
Brazil	0.11	0.14	2.58	0.00	0.00	0.55
Malaysia	0.00	0.43	1.85	0.02	0.00	0.54
Turkey	1.93	0.01	0.02	0.00	0.00	0.39
Singapore	0.00	0.45	0.58	0.12	0.00	0.33
Spain	0.00	0.21	0.27	0.53	0.00	0.22
Belgium	0.00	0.08	0.18	0.88	0.00	0.20
New Zealand	0.03	0.09	0.16	0.61	0.00	0.17
Czech Republic	0.00	0.00	0.90	0.00	0.00	0.16
Mexico	0.00	0.32	0.00	0.00	0.00	0.15
Finland	0.30	0.01	0.37	0.05	0.00	0.14
Australia (Re-imports)	0.03	0.16	0.11	0.10	0.00	0.11
Denmark	0.00	0.00	0.01	0.74	0.00	0.11

Source ABS 2008

More detailed compression-ignition internal combustion piston engine import data were obtained from the ABS for the period July to December 2008. These data differentiated between three main diesel engine categories and a range of power bands, as follows: 'marine' (4 power bands ranging from less than 125 kW to greater than 375 kW), 'other' (9 power bands from less than 55 kW to greater than 1,500 kW) and 'gen sets' (4 power bands, less than 7 kVA to greater than 500 kVA). The following observations were made in respect of the detailed loose diesel engine import data acquired:

- The main exporters of non-road diesel engines to Australia, and their respective market share in terms of numbers of engines, were: China (31%), Japan (25%), United Kingdom (11%), USA (10%) and Italy (6%).
- All of the main exporters of non-road diesel engines (Japan, USA, China, UK, Italy, Germany) were noted to cover most power bands.
- China dominates gen set imports, with other significant importers being the UK, Singapore, USA and Japan.

- Japan was the largest source of 'other' diesel engines (excluding marine engines and gen sets), with other key exporters including China, Germany, Italy, the UK and the USA.
- 85% of the 'other' diesel engine imports occur in the power bands less than 150 kW, with most of the sales being in the less than 55 kW power band. Imports from Japan, Italy and the UK are strongly represented in this category.
- Japan, the USA and Sweden were the main countries of origin of 'marine' diesel engines, with the USA a significant source of larger engines.

Agricultural tractor imports into Australia, by country or origin and engine rating, are given in **Appendix B**. The US and Japan cover all or most of the power bands, whereas other country imports tend to fall into smaller engine sizes (e.g. Canada, Vietnam), middle range power bands (China, India, Republic of Korea) or larger power bands (Austria, Germany).

5.3.2 Used Diesel Engine/Equipment Imports

The ABS import data includes both new engines/equipment and used engines/equipment imported into Australia for sale. To identify the number of used engines/equipment reference was made to data obtained from the Machinery & Military National Co-ordination Centre of the Australian Quarantine and Inspection Service (AQIS).

Based on consultation with industry, and on the comparison of import/export and new engine/equipment sales data, the number of used or reconditioned diesel engines imported into Australia appear to be relatively small. One industry representative indicated that the availability of low cost (and potentially low quality) engines was the main reason for the limited market for used imports.

Data obtained from AQIS for 2008 confirms that used diesel imports are relatively small, comprising about 1,650 units (approximately 3% of total sales) (**Table 21**). It is however important to note that used engines/equipment are only identified as being such based on the word "used" being included on the paperwork accompanying imports. This number should therefore be viewed as a lower estimate of the number of used non-road diesel engines/equipment entering Australia annually.

Table 21: Breakdown of used non-road diesel engine/equipment imports into Australia in 2008		
Market Segment	**Equipment Type**	**No. of Used Imports (2008)**
Agricultural	Agricultural tractors	104
Industrial (Heavy Equipment)	Mechanical shovels, excavators and shovel loaders	231
	Dozers	38
	Graders and levellers	6
	Tamping machines and road rollers	10
Industrial (General)	Cranes	41
Marine	Marine propulsion diesel engines	2
Vehicle Propulsion	Vehicle propulsion diesel engines (includes on-road and off-road vehicle classes)	1,199
Other	Other diesel engines	18
Total		**1,649**

Data Source: AQIS, 2009

Over 70% of the used engines/equipment comprised vehicle propulsion engines, including engines for both on-road and non-road vehicles. Such engines are however retained for consideration since they may be applied within non-road applications despite having been initially manufactured for the on-road market.

Heavy industrial (construction, mining) equipment represents 20% of used non-road diesel imports, and is dominated by excavators and loaders.

About a hundred agricultural tractors (6% of used non-road diesel imports) were identified, with the remaining 1% comprising marine and other diesel engines unrelated to vehicle propulsion.

5.3.3 Non-road Diesel Engine Exports

Given that diesel engines are not locally manufactured it is pertinent to consider the number of engines which are exported annually from Australia in order to assess the magnitude of local sales. Based on the comparison of import and export numbers, it may be expected that local sales of loose non-road diesel engine and gen sets would be in the range of 20,000 units.

Table 22: Comparison of non-road diesel engine import and export data for 2008			
Broad Diesel Engine Classification	**Imports (2008)**	**Exports (2008)**	**Imports – Exports (2008)**
Marine (all engine ratings)	4,538	3,821	717
Power Gen Sets	16,638		
Other Engines	11,932	9,587(a)	18,983(a)
Total	**33,108**	**13,408**	**19,700**

Source: ABS 2009.

(a) Export data only available for broader category which includes power gen sets and other engines (excluding marine engines).

5.4 Non-road Diesel Engine and Equipment Sales in Australia

5.4.1 Description of Sales Data Sets

The ERG International Loose Diesel Engine and Gen Set Sales Data Set is described in **Appendix C**. In addition sales data were collected directly from certain non-reporting industries to fill identified data gaps.

The ERG International 'Construction and Mining Equipment Sales Data Set' for 2008, includes the following equipment types:

- Hydraulic Excavators
- Mini Excavators
- Wheel Loaders
- Dozers
- Crawler Loaders
- Motor Graders
- Scrapers
- Dump Trucks – Rigid and Articulated
- Backhoe Loaders
- Skid Steer Loaders
- Road Rollers
- Log Skidders

It is evident from the type of equipment included and the number of units sold that the data represents not only equipment used in the construction and mining sectors but also equipment used in industrial, commercial and forestry applications.

Tractors represent the most significant non-road diesel equipment type operating in the agricultural sector in terms of equipment numbers. Annual agricultural tractor sales data were obtained from the TMA for the 1997 to 2008 period.

Given that the three sales data sets obtained were identified to cover 90% of imported non-road diesel engines/equipment types, estimates were made for the remaining types based on previous studies and documented historical sales as discussed in the subsequent subsection.

5.4.2 Estimated Non-road Diesel Engine/Equipment Sales

Non-road diesel engine/equipment sales estimates for 2008 is given in **Table 23**, with the basis for the sales estimates provided.

Table 23: Estimated Non-road Diesel Engine/Equipment Sales for 2008

Market Segment	Engine/Equipment Description	Number of Units Estimated to be Sold (2008)	Basis for Estimate
Industrial (Industrial, Commercial, Construction, Mining)	Engines for Construction & Mining Equipment	3,422	(a)
	Engines for Industrial Pumps	2,903	(a)
	Engines for 'Other' Industry Equipment(f)	3,726	(a)(h)
	Engines for Miscellaneous Industry Applications	1,611	(a)
	Tractors (expected to include airport equipment)	562	(b)
	Forklifts	609	(b)
	Cranes and lifting equipment	2,850	(b)(h)
	Heavy Construction, Mining, Industrial and Commercial equipment (e.g. loaders, rollers, dumpers)	12,441	(c)(h)
Agricultural	Engines for Pumps & Irrigation	3,964	(a)
	Engines for agricultural vehicles	20	(a)
	Engines for 'Other' agricultural applications(g)	60	(a)
	Agricultural tractors	12,101	(d)(h)
	Combine harvester-threshers	538	(d)
	Windrowers	66	(e)
	Self Propelled Sprayers	333	(d)
	Balers	0	(j)
Power Generation (various markets)	Power Gen Drives - Prime Power	1,320	(a)
	Power Gen Drives - Standby Power	1,326	(a)
	Power Gen Drives - Marine Auxiliary	118	(a)
	Power Gen Sets - Prime Power	1,382	(a)
	Power Gen Sets - Standby Power	1,190	(a)
	Power Gen Sets - Marine Auxiliary	202	(a)
	Power Gen Sets - Miscellaneous	869	(a)
Lawn and Garden	Ride on or tractor lawn mowers	1,900	(b)
Light Commercial	Welders, air compressors, pressure washers	1,000	(b)
Marine (<37 kW)(i)	Propulsion engines for pleasure boats (<37 kW)	440	(a)
	Propulsion engines for work boats (<37 kW)	28	(a)
	Propulsion engines for fishing boats (<37 kW)	6	(a)
	Marine propulsion engines (not specified) (<37 kW)	17	(a)
Forestry	Log Skidders	30	(c)
Potential non-road applications	*Vehicle Propulsion (used)*	*1,199*	*(h)*
TOTAL		56,233	

(a) ERG International 'Loose Diesel Engine and Gen Set Sales Data' for 2008, supplemented by data from several industries not reporting to ERG. Reference should be made to Appendix C for a definition of the application categories.

(b) Assumed equivalent to estimated imports (Table 19).

(c) ERG International 'Construction and Mining Machinery Sales Data Set' for 2008. Specific equipment types include: Hydraulic Excavators, Mini Excavators, Wheel Loaders, Dozers, Crawler Loaders, Motor Graders, Scrapers, Dump Trucks – Rigid and Articulated, Backhoe Loaders, Skid Steer Loaders and Road Rollers.

(d) Sales data obtained for 2008 from the TMA.

(e) Based on 2004 sales data, taking into account PAE (2005) estimate that 99.2% of in-service combines are diesel.

(f) Includes engines for waste removal equipment, road sweeping and cleaning equipment, hydraulic power packs and welding sets.

(g) Includes engines for hay making machinery, oil tresses, lawn and garden outdoor power equipment.

(h) Includes used engine imports. Data received from AQIS, 2009.

(i) Only marine engines smaller than 37 kW were included in this study, given that such engines are covered specifically by US non-road diesel emission standards. (The US regulate marine diesel engines above 37 kW under marine specific US-EPA rulemakings.)

(j) No self-propelled balers are used in Australia according to the TMA (information received October 2009).

All used vehicle propulsion engines (for on-road and non-road vehicles) were included in the sales figures given that such engines may find their way into a range of non-road applications (e.g. agricultural applications).

5.4.3 Review of Sales Data Completeness

To determine the completeness of the sales figures compiled, reference is made to the import data presented previously (**Section 5.3**). Whereas non-road diesel engine/equipment imports are estimated to be of the order of 73,900, non-road diesel engine/equipment sales are quantified as being 56,233 (i.e. 76% of imports). This difference is mainly due to the lower sales figures for loose diesel engines and gen sets (~75% of imports), and agricultural tractors (~60% of imports).

Reasons why loose diesel engine and gen set sales figures may be lower than import numbers include the following:

- Some imported engines are not sold in Australia, but are en route elsewhere.
- Sales information is not made available from all loose diesel engine and power generation set suppliers.
- The timing between engine imports and engine sales is likely to be offset, introducing uncertainties in the comparison of figures for the same period.

Non-road diesel engine and gen set exports were of the order of 13,400 during 2008 (refer to **Section 5.3.3**). This is expected to be the main reason for the ~7,000 unit difference in sales and import figures. The diesel engine sales data set compiled is therefore expected to be substantially complete and representative.

The reason for the difference in the import and sales data sets for agricultural tractors is not clearly understood. According to the TMA, the sales data set it collates accurately represents the number of new tractors sold in 2008 (i.e. ~12,000), to within tens of tractors. Comprehensive agricultural sales data is available since at least 1997. The import figure of ~19,000 reflects information contained on import paper work and is not necessary representative of working agricultural tractors (TMA personal communication). This import number is given as potentially including toy tractors, used/second hand tractors imported for sale and/or mistakes in paper work. According to the executive director used / second hand tractor sales numbered thousands of machines annually a few years ago, but has diminished substantially and is now expected to be a few hundred tractors sold each year. This was confirmed based on the used equipment import figures received from AQIS, with only 104 used agricultural tractors listed as being imported during 2008 (**Section 5.3.2**).

Following consultation with industry it was decided to retain the sales figures obtained from the TMA as being representative of the local market rather than to scale the sales figures to reflect import numbers.

Estimated annual sales of non-road diesel engine/equipment in 2008 (56,233) represents about 9% of the extrapolated in-service non-road diesel population for this year (~620,000). This percentage is comparable to that documented for the United States (10%)[(48)].

48 Over 650,000 pieces of diesel equipment, which are covered by non-road diesel rulemaking, are reported to be sold in the United States each year. The in-service numbers are currently given as six million pieces of non-road diesel equipment. Non-road diesel equipment sales therefore comprise about 10% of in-service non-road diesel equipment numbers in the US.

5.4.4 Market Share by Sector and Major Applications

Non-road diesel engines/equipment sold in Australia by market segment, are illustrated in **Figure 7**.

Broad industrial applications (including industrial, commercial, construction and mining applications) are estimated to account for 50% of non-road diesel engine/equipment sales. Agricultural applications represent around 30%, and Power Generation 11%. Other applications include Lawn and Garden (3.4%), Light Commercial (1.8%), Marine Propulsion (0.9%) and Forestry (0.1%).

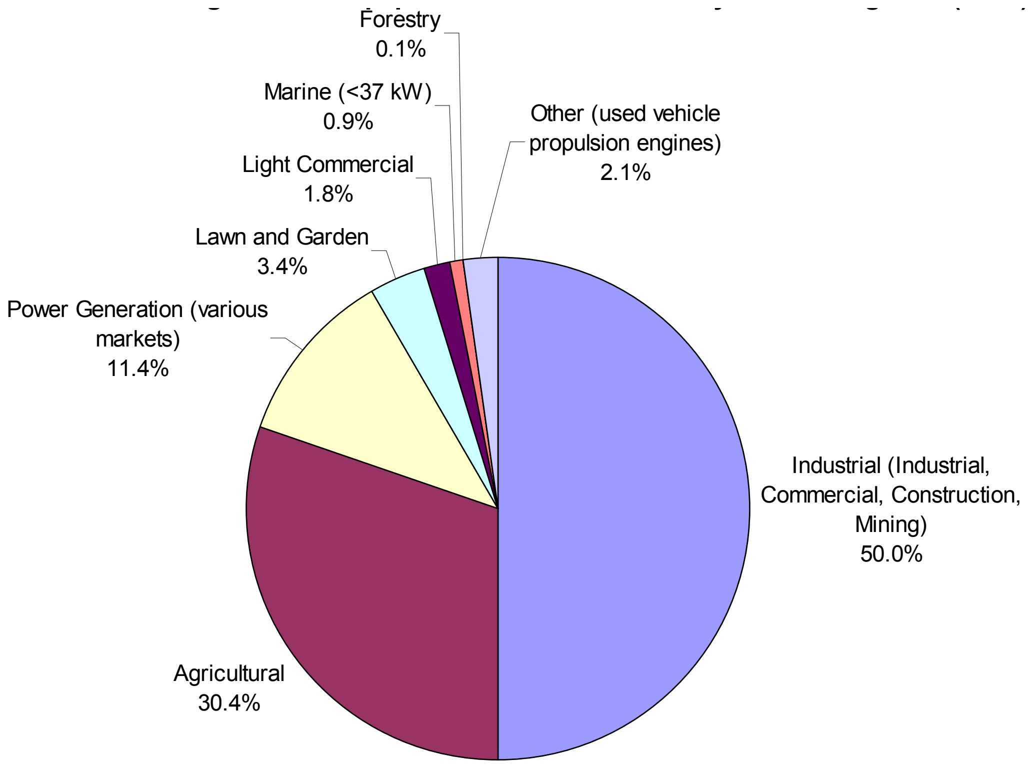

Figure 7. Non-road diesel engines and equipment sold in Australia (2008) by market segment (as numbers of units sold)
Data Sources: ERG International, 2009; TMA, 2009; supplemented by additional industry data and estimates

Non-road diesel engines/equipment sold in Australia by application (equipment type), are illustrated in **Figure 8**. Heavy Construction, Mining, Industrial and Commercial Equipment and Agricultural Tractors represent key applications.

The Heavy Construction, Mining, Industrial and Commercial Equipment application category given in this table is further broken down into equipment types in **Figure 9**. Sales were dominated by hydraulic excavator sales, accounting for 38% of equipment nationally. Other significant equipment types included: skid steer loaders (27%), road rollers (10%), wheel loaders (9%), dump trucks (6%), motor graders (4%) and backhoe loaders (3%).

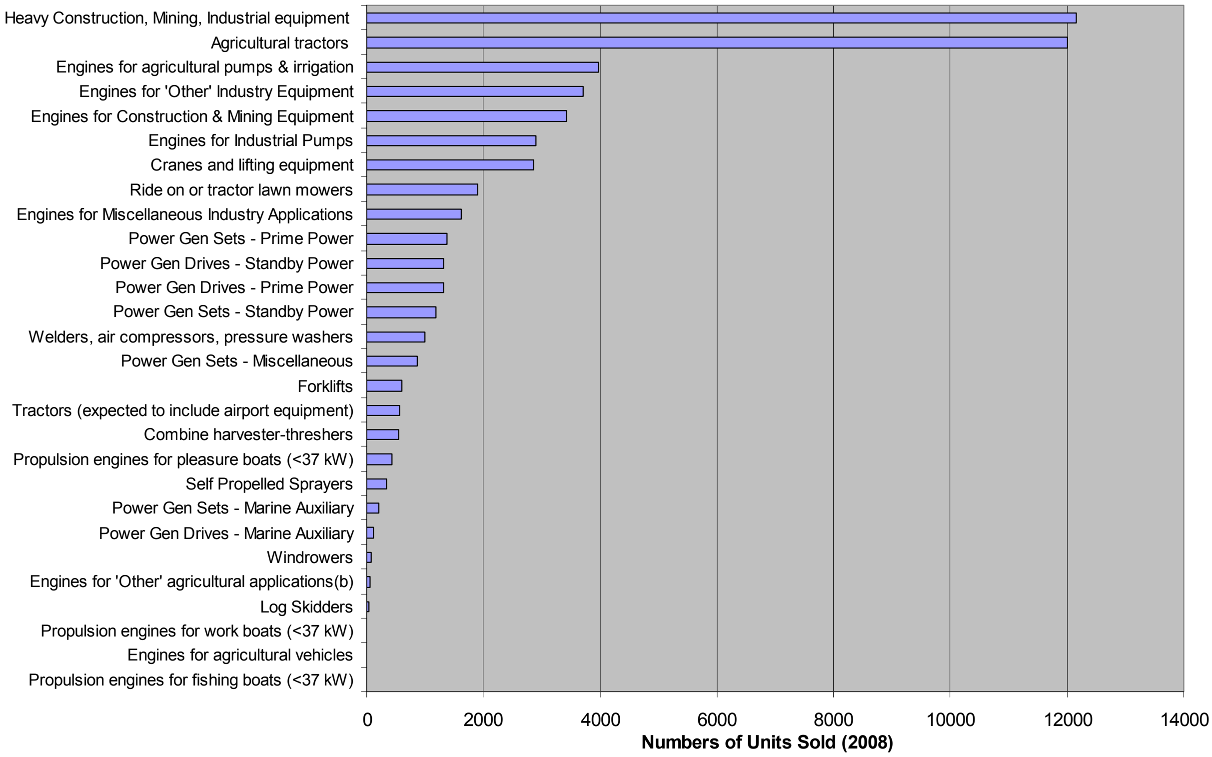

Figure 8: Diesel engine/equipment sales in Australia by application (2008)

Data Sources: ERG International, 2009; TMA, 2009; supplemented by additional industry data and estimates

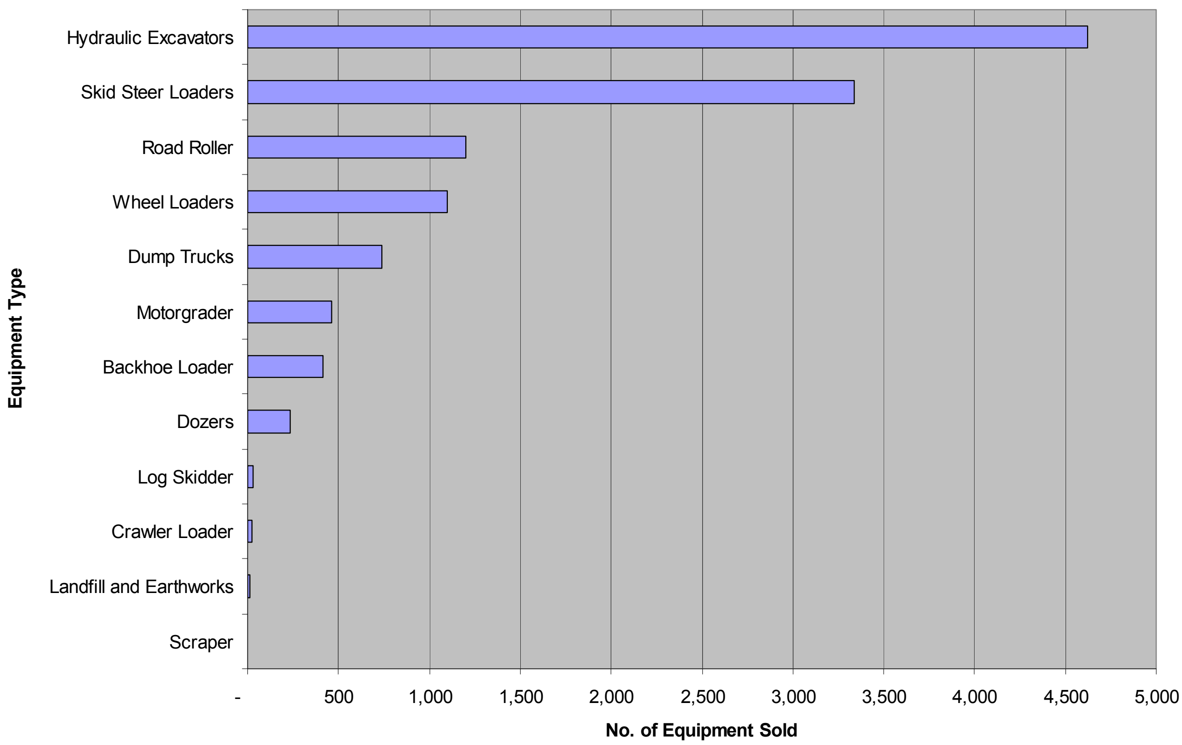

Figure 9: Construction and Mining Equipment sales in Australia (2008) by equipment type

Data Source: ERG International, 2009.

Background information on certain non-road diesel engine/equipment applications are given in **Appendix D**.

5.4.5 Market Share by Engine Rating

Non-road diesel engines differ from on-road engines in that they range widely in engine size and power ratings. The pieces of equipment in which engines are placed are very diverse, and the same engine can be used in widely different equipment applications (e.g. same engine can be used in a backhoe or drill rig or air compressor).

Detailed engine rating data were obtained for 100% of the estimated loose diesel engines sales, 90% of the heavy industrial (construction, mining) equipment sales and 100% of the agricultural tractors sales. Engine ratings were inferred for lawn and garden equipment based on equipment inventoried during the NSW GMR Emissions Inventory[49]. Combined, these data permitted the characterisation of 85% all engine/equipment sales during 2008.

Diesel engine and heavy industrial (construction, mining) equipment sales by engine rating is illustrated in **Figure 10**, with agricultural tractor sales by engine rating given in **Figure 11** for recent and previous years. Cumulatively, for loose diesel engines and gen sets, about 35% are less than 10 kW, 56% are less than 25 kW, 76% are less than 75 kW, 90% are less than 200 kW. In comparison, only 1% of heavy industrial (construction, mining) equipment have engines which are less than 10 kW, 15% are less than 25 kW, 61% are less than 75 kW, 86% are less than 200 kW. The loose diesel engines comprise a larger number of smaller engines due to such engines being sold into a variety of markets including the agricultural market where small pump engines dominate. About 12% of agricultural tractor sales during 2008 fell in the less than 15 kW range, with 76% of tractors sold having an engine rating lower than 75 kW.

Engine ratings across all non-road diesel engines and equipment for which power rating data are available (i.e. 85% of 2008 sales) are summarised in **Table 24**. Small engines (less than 19 kW) make up almost 30% of the total market, with 3% of engines sold falling within the greater than 560 kW range. These engine categories are subject to non-road diesel emission regulation in the United States but are excluded from such regulations by the EU.

49 NSW DECCW (2007). Air Emissions Inventory for the Greater Metropolitan Region in New South Wales, New South Wales, Department of Environment, Climate Change and Water, Sydney.

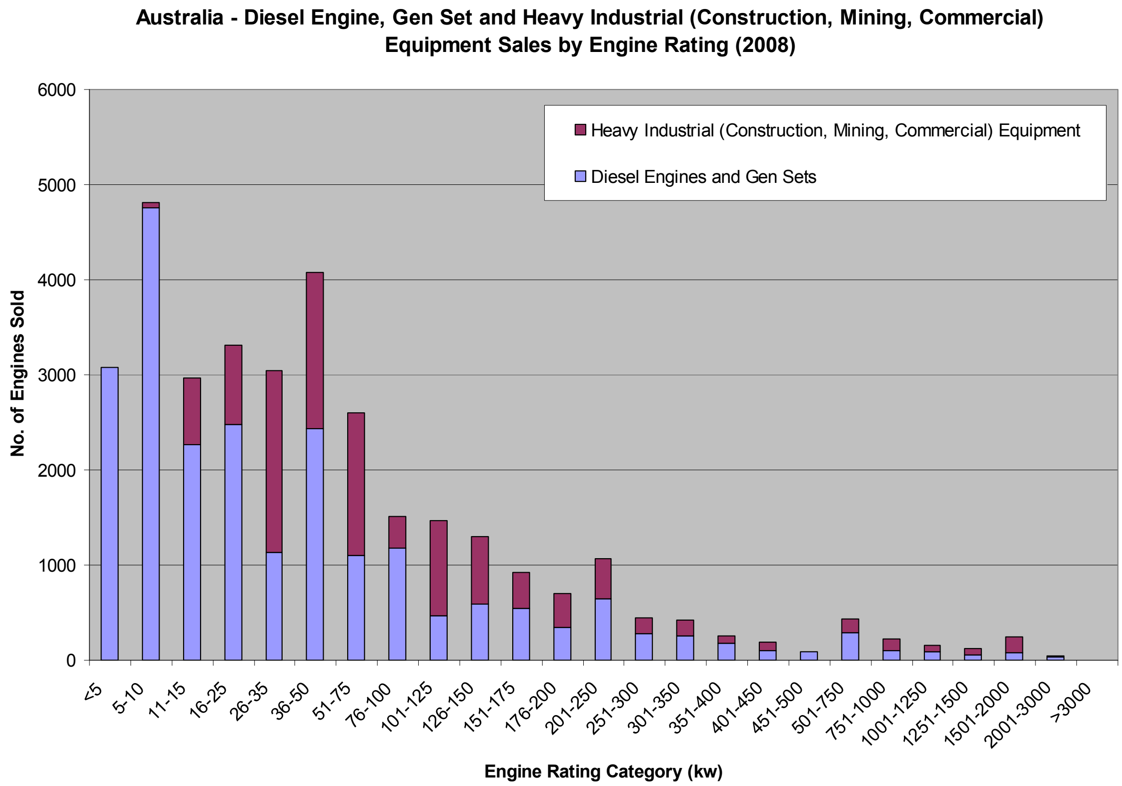

Figure 10: Diesel engine, gen set and heavy industrial equipment sales (2008) by engine rating
Data Source: ERG International, 2009

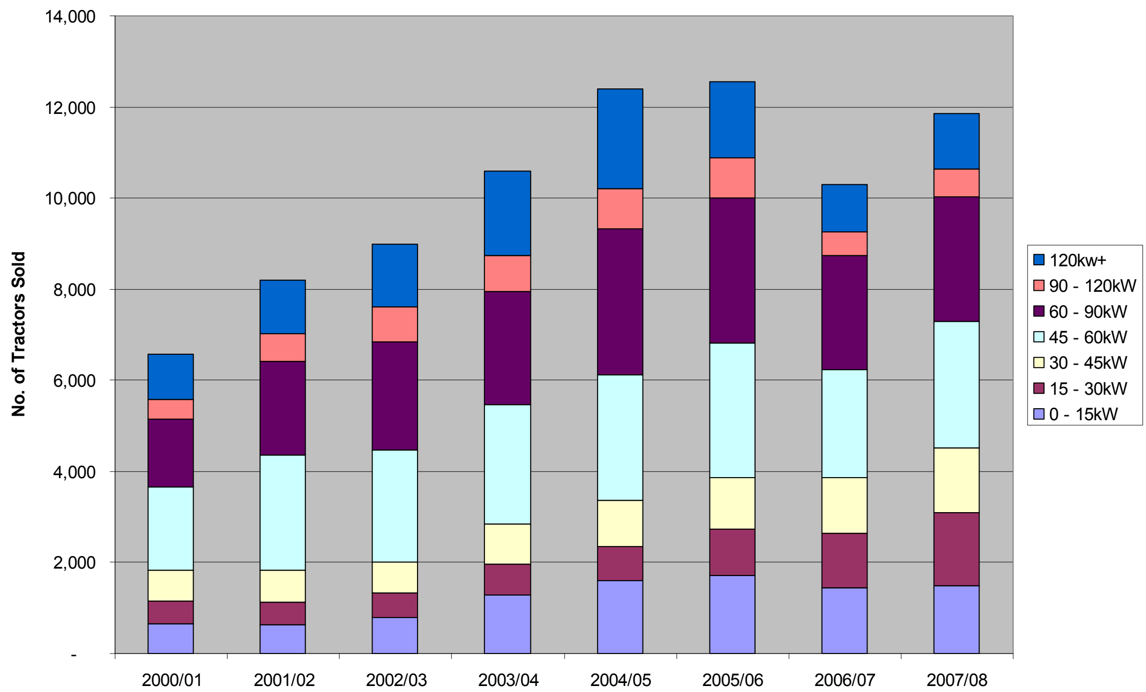

Figure 11: Annual tractor sales in Australia by power rating for the 2000/1 to 2007/8 period
Data Source: TMA, 2009

Table 24: Engine Ratings of Non-road Diesel Engines/Equipment Sold in Australia in 2008

% within Engine Rating Category		Cumulative % Below Engine Rating	
<8 kW	19	<8 kW	19
8-19 kW	11	<19 kW	30
19-37 kW	16	<37 kW	46
37-56 kW	18	<56 kW	64
56-130 kW	14	<130 kW	78
130-225 kW	9	<225 kW	87
225-560 kW	9	<560 kW	97
>560 kW	4		

Data Sources: TMA, 2009; ERG International, 2009; industry.

Note: Agricultural tractor engine ratings were inferred from broader categories. Annual engine rating for a large portion of the loose diesel engines and gen sets were inferred from detailed engine rating data for the July to December 2008 period.

Non-road diesel engine and equipment sales by application and engine rating is illustrated in **Figure 12** and given as cumulative percentages in **Table 25**.

Agricultural pumps and irrigation applications are dominated by small engines, with 76% being less than 8 kW and 80% less than 19 kW. In comparison, industrial pumps tend to comprise larger engines with only 1% of engines being less than 8kW and 9% being less than 19 kW.

A wide range of engine sizes are used for construction and mining equipment and other industrial applications (less than 10 kW to greater than 1,000 kW), reflecting the diversity of the equipment used by the industrial market segment. About 86% of heavy industrial (construction, mining) equipment falls in the 19 kW to 560 kW range, with only 6% less than 19 kW. It is interesting to note that loose diesel engines reported to be sold into the construction and mining equipment market comprise a significantly larger proportion of small engines, with 38% being less than 8 kW. This may be due to smaller engines having shorter useful lives and require more frequent replacement, or be indicative of engines reported for construction and mining application being applied for other applications.

Almost 60% of power generation drives sold are in the less than 19 kW range, compared to 28% of gen sets. Gen sets sold also include a higher percentage (11%) of greater than 560 kW engines compared to power generation drives (2%).

In line with US non-road diesel regulations only marine propulsion engines in the range under 37 kW are included in the study and almost 40% of them are under 19 kW.

About 20% of agricultural tractors and over 60% of ride on / tractor mowers are estimated to fall in the less than 19 kW range.

Table 25: Engine Ratings of Non-road Diesel Engines/Equipment Sold in Australia in 2008 by Application

Application	Cumulative % Below Engine Rating						
	<8 kW	<19 kW	<37 kW	<56 kW	<130 kW	<225 kW	<560 kW
Engines for Construction & Mining Equipment	38	39	50	54	64	77	96
Heavy Construction, Mining, Industrial and Commercial equipment	1	5	20	44	51	68	91
Agricultural Pumps and Irrigation	76	80	87	92	97	99	100
Power Generation Drives	44	59	78	83	91	95	98
Power Generation Sets	20	28	43	60	72	81	89
Marine Propulsion Engines (<37 kW)(a)	17	39	100	100	100	100	100
Ride On / Tractor Mowers	28	64	100	100	100	100	100
Agricultural Tractors	6	19	33	62	89	97	100
Other Industrial Engines	27	47	63	80	94	96	99
Industrial Pumps	1	9	34	48	77	89	98
TOTAL ACROSS APPLICATIONS (%) (weighted by numbers of units sold)	19	30	46	64	78	87	97

Data Sources: TMA, 2009; ERG International, 2009; industry; DECCW 2007

Note: Agricultural tractor engine ratings were inferred from broader categories. Annual engine rating for a large portion of the loose diesel engines and gensets were inferred from detailed engine rating data for the July to December 2008 period.

(a) Only marine engines smaller than 37 kW were included in this study, given that such engines are covered specifically by US non-road diesel emission standards. (The US regulate marine diesel engines above 37 kW under marine specific US-EPA rulemakings.)

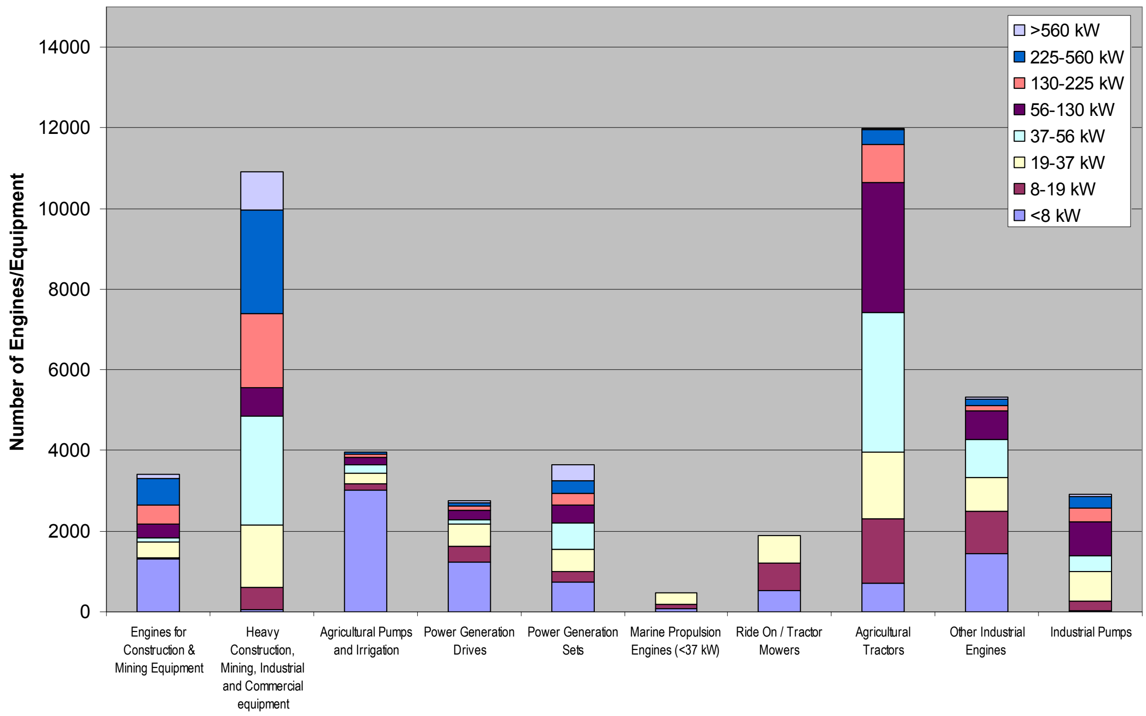

Figure 12: Non-road diesel engine/equipment sales by engine rating and market application

Data Sources: TMA, 2009; ERG International, 2009; industry; DECCW 2007

Note: Agricultural tractor engine ratings were inferred from broader categories. Annual engine rating for a large portion of the loose diesel engines and gensets were inferred from detailed engine rating data for the July to December 2008 period.

5.4.6 Trends in Non-road Diesel Engine/Equipment Sales

Historical sales data were only available for loose diesel engines, and for agricultural tractors, as illustrated in **Figure 13** and **Figure 14** respectively. Sales of heavy industrial (construction, mining) equipment and 'other' equipment are depicted in **Figure** 14 to illustrate the significance of missing data.

National sales of loose diesel engines peaked in 1986 (22,260 diesels sold nationwide)(**Figure 13**). The extent of non-road diesel engine/equipment sales is projected to have grown over the last decade, with the post 2005 reduction in loose diesel engine sales being off-set by the increase in agricultural tractor sales (**Figure 14**).

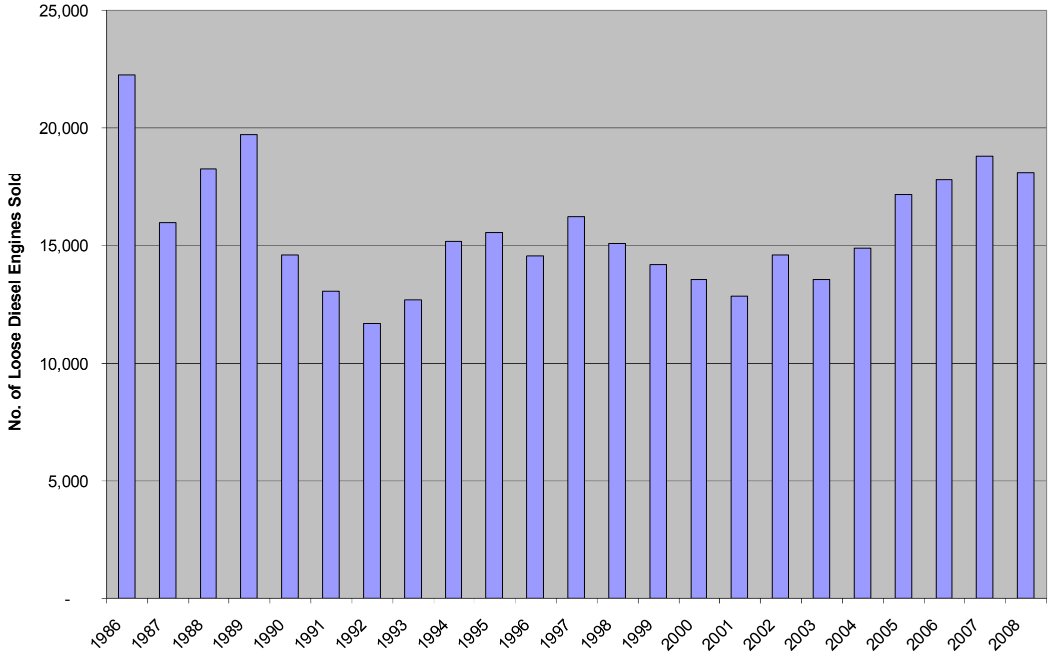

Figure 13: Trends in loose diesel engine sales in Australia and NSW (1986 to 2008)
Data source: ERG International, 2009

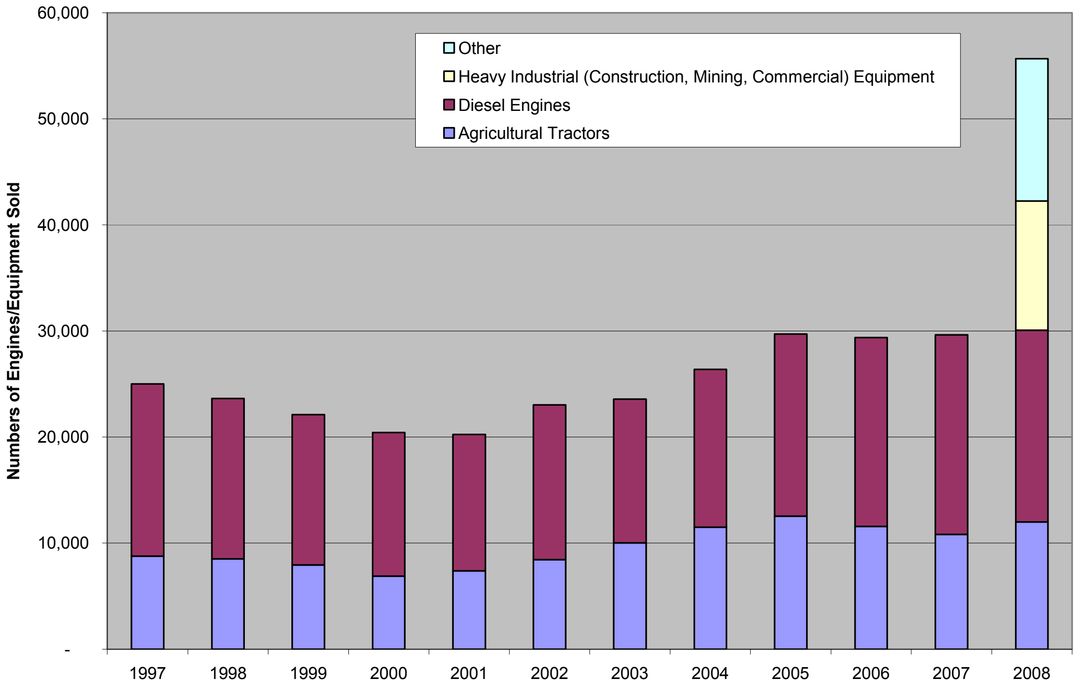

Figure 14: Trends in non-road diesel engine/equipment sales in Australia (1997 to 2008). Only agricultural tractor and loose diesel engine sales data are available prior to 2008.
Data source: ERG International, 2009; TMA, 2009; industry

Non-road diesel engine/equipment sales data by state was available for 76% of total numbers sold. The bulk of the sales are within Queensland (30%), NSW (25%), Victoria (21%) and Western Australia (14%) (**Figure 15**).

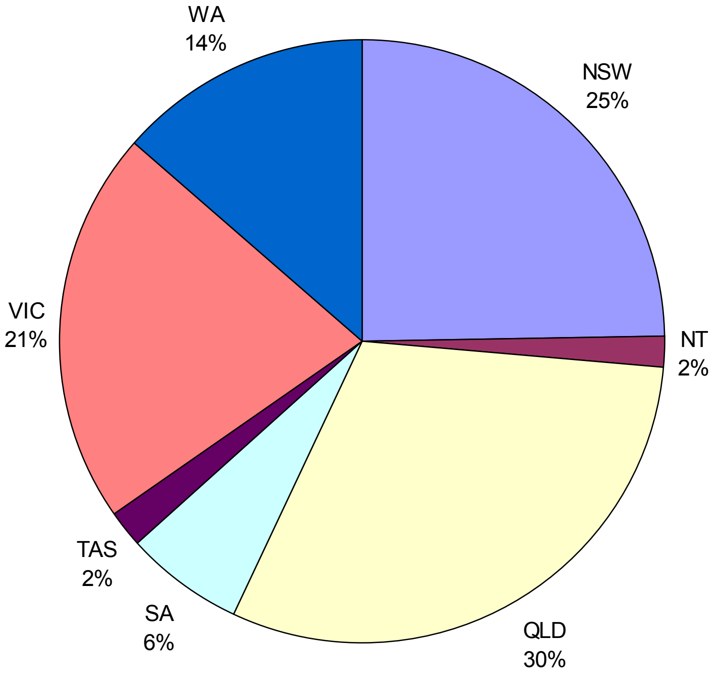

Figure 15: Non-road diesel engine/equipment sales in Australia (2008) by state. (% of units sold)
Data Source: ERG International, 2009; TMA, 2009; Industry

5.4.7 Market Share by Product Brand

Diesel ('Loose') Engines)

No diesel engines are manufacturered within Australia, with all engines being imported for sale locally.

Based on the available loose diesel engine sales data, it is evident that the market is dominated by a few leading brands, with five brands accounting for over 80% of the reported engine sales data across market segments.

Heavy Industrial (Construction, Mining) Equipment

Three brands account for about 50% of national heavy industrial (construction, mining) equipment sales. The top 10 brands account for 80% of the inventoried market share.

Agricultural (Tractors and Machinery)

Close to 20 suppliers of new tractors in Australia were identified during the study, of which there are a small number of leading brands which have a significant market share. Detailed information on market share could however not be obtained.

Harvesters and windrower tractors and other self-propelled agricultural equipment are also imported into Australia. Sprayers and other smaller equipment are either imported or manufactured in Australia, however locally manufactured units are fitted with imported engines.

Seven suppliers of self propelled sprayers and windrower tractors in Australia were identified during the course of study. Detailed information on market share could however not be obtained.

5.5 Emissions Performance of Non-road Diesel Engines and Equipment

5.5.1 Data Collation Method

The emission performance for non-road diesel engines and equipment were characterised based on a range of methods including direct industry surveys, consultations with industry and industry associations, review of previous studies and collation of publicly available product information.

Identified non-road diesel engine and equipment suppliers were surveyed to obtain emission performance information, with emphasis on brands with significant market share. The TMA assisted by surveying the agricultural sector, with heavy industrial (construction, mining) and diesel engine and gen set suppliers being surveyed by ENVIRON. Details of the surveys are as follows:

- Survey of Diesel Engine and Gen Sets suppliers (estimated to be responsible for about 41% of total non-road diesel engine/equipment sales data):
  - Surveys were sent to 13 companies which represent Australian representatives of known brands. These companies cover over 20 brands sold in Australia.
  - Companies provided data on 16 brands, including the four leading brands in terms of total numbers of engines sold during 2008. This data was supplemented by publicly available information regarding the emission performance of a further 2 brands.
  - Excluding marine engines greater than 37 kW[50], the total number of relevant engines for which emission performance information was collected was 19,786.
  - Used engine imports were assumed to be non-compliant.
- Survey of Heavy Industrial (Construction, Mining) Equipment suppliers (estimated to be responsible for about 22% of total non-road diesel engine/equipment sales data):
  - Surveys were sent to Australian representatives of 21 of the 29 brands known to be sold in Australia. These 21 comprise 99% of the sales data collated for this market segment.
  - Data were obtained from companies across 15 brands, including the two largest brands in terms of numbers of units sold during 2008. Publicly available emission performance information was sourced for a further 4 brands.

50 Only marine engines smaller than 37 kW were included in this study, given that such engines are covered specifically by US non-road diesel emission standards. (The US regulate marine diesel engines above 37 kW under marine specific US-EPA rulemakings.)

- Emission performance information was collected for 10,931 pieces of construction and mining equipment sold during 2008.
- Used equipment imports were assumed to be non-compliant.

- Survey of Agricultural Equipment suppliers (estimated to be responsible for about 25% of total non-road diesel engine/equipment sales data):
  - The TMA has undertaken a survey with its members to obtain the emission performance information required for the current study. Emission performance is not readily known by the TMA, nor by various individual distributors and needed to be sourced from manufacturers.
  - Fourteen out of eighteen identified agricultural suppliers, including the leading brands, and six out of seven identified suppliers of self propelled sprayers and windrower tractors in Australia are members of the TMA.
  - Detailed emission compliance information from the industry survey was not yet available from the TMA at the time of writing this report, requiring that reference be made to the general preliminary observations made by TMA. The TMA executive director states that all of the ~12,000 new tractors sold are at least US Tier 1 or equivalent compliant, with the overwhelming majority being at least US Tier 2 or equivalent and higher.
  - For the purpose of the current assessment it was conservatively assumed that 20% of the new agricultural tractors sold are US Tier 1 compliant, 70% US Tier 2 compliant and 10% Tier 3 compliant. Used tractor imports were assumed to be non-compliant.
  - The emission compliance status of other diesel powered agricultural equipment is not known.
- Lawn and Garden, Light Commercial and General Industrial Equipment (estimated to be account for about 12% of total non-road diesel engine/equipment sales data):
  - Market share information could not be obtained for diesel-powered lawn and garden equipment, light commercial equipment (air compressors, pressure washers, welders) and general industrial equipment (including cranes and lifting equipment, airport tractors and forklifts).
  - Despite consultations with a number of industry suppliers regarding the emission performance of their products, the lack of market share information made it impossible to accurately characterize the compliance status of such equipment.
  - Based on information provided by some suppliers, publicly available information, and observations made by previous studies, a lower bound (conservative) estimate was made of the compliance status of equipment.

The accuracy of information was checked through inter-company comparisons, references to publicly available product information and through discussions and clarifications with industry representatives having provided data. Generally however the information reported by industry was taken to be accurate, with no documentation (e.g. certification records) having been requested to be provided to substantiate figures reported.

5.5.2 Data Completeness

Emission performance information completeness (based on number of engines/equipment characterized) by market segment is outlined in **Table 26**.

Overall the emission compliance status of 91% of inventoried non-road diesel engine/equipment sold into the Australian market during 2008 were either established based on industry direct survey data or estimated. Industry survey data received allowed for the characterization of 50% of engines/equipment, with the remaining 41% being estimated based on methods outlined previously. The compliance status of about 9% of engines/equipment could not be established, comprising primarily of power generation drives and sets and agricultural equipment (excluding agricultural tractors).

Table 26: Emission performance information completeness (%) by market segment

Market Segment	Quantified / Estimated			Unknown
	Industry Data Received	Estimate	Total (Quantified; Estimated)	
Agricultural	21	71	92	8
Forestry(a)	100		100	0
Industrial	69	25	94	6
Marine(a)	100		100	0
Power Generation Drive	61	16	77	23
Power Generation Sets	62	1	63	37
Vehicle Propulsion(c)		100	100	
Lawn and Garden		100	100	
Light Commercial		100	100	
Total (weighted by equipment numbers)	50	41	91	9

(a) Sales figures and emission performance information primarily confined to skid loaders.
(b) Figures confined to reported marine propulsion engines (less than 37 kW) sales.
(c) Used vehicle propulsion engines assumed to be used for non-road applications.

5.5.3 Emission Performance of Non-road Diesel Engines/Equipment

The emission performance status of engines/equipment was assessed based on whether they complied with international emissions limits such as those issued by the US and EU for non-road diesel engines.

In the case of engines/equipment given as complying with a specific standard, it was determined whether certification of compliance had been achieved. Certification comprises the engine/equipment having the necessary documentation, certified by the competent authority, that the engine/equipment supplied meets the required specifications.

The emissions performance of non-road diesel engines/equipment inventoried as being sold into Australia during 2008, given in terms of likely *compliance* with international standards, is illustrated in **Figure 16** and given by market segment in **Table 27**.

About 22% of non-road diesel engines were estimated to be non-compliant with international standards or only compliant with 1996-2000 US Tier 1 (EU Stage I) emission standards. A further 9% was unknown.

A significant proportion (47%) of engines were found likely to be compliant with older 2000-2006 US Tier 2 (EU Stage II) standards.

About 5% of engines were reported by industry as meeting 2008 US Tier 4 interim standards.

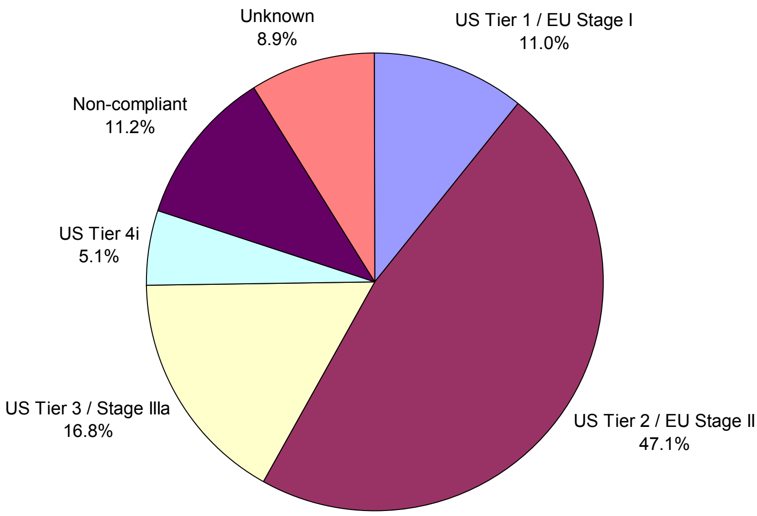

Figure 16: Emissions performance status of non-road diesel engines/equipment sold into Australia during 2008 (in terms of *compliance* with international standards). Implementation dates for US emission standards are as follows: Tier 1 (1996-2000), Tier 2 (2001-2005), Tier 3 92006-2008), Tier 4i (2008) and Tier 4 final (2011-2015).

Table 27: Emissions performance status of non-road diesel engines/equipment sold into Australia during 2008 by market segment.
(Market segments are specified as compliance with international standards) (a)

Segment	Compliance Status Unknown	Non-compliant	US Tier 1 / EU Stage I	US Tier 2 / EU Stage II	US Tier 3 / Stage IIIa	US Tier 4i	No Longer Sold	Total
	No. of Engines/Equipment – Compliance Status		Compliant with Following Emission Standards:					
Agriculture	1,204	1,646	2,506	10,424	1,302	-	-	17,082
Forestry	-	6	-	9	15	-	-	30
Industrial	1,778	3,051	3,276	10,110	7,371	2,568	13	28,166
Lawn and Garden	-	-	380	1,330	190	-	-	1,900
Light Commercial	-	-	-	1,000	-	-	-	1,000
Marine (<37 kW) (b)	-	-	6	436	8	24	-	474
Other (used vehicle propulsion engines)	-	1,199	-	-	-	-	-	1,199
Power Generation Drives	634	40	-	1,843	11	236	-	2,764
Power Generation Sets	1,362	382	3	1,322	542	32	-	3,643
All Non-road Diesel Engines/Equipment	4,978	6,324	6,171	26,474	9,439	2,860	13	56,258
	% of Engines/Equipment – Compliance Status		Compliant with Following Emission Standards:					
Segment	Compliance Status Unknown	Non-compliant	US Tier 1 / EU Stage I	US Tier 2 / EU Stage II	US Tier 3 / Stage IIIa	US Tier 4i	No Longer Sold	Total
Agriculture	7.0	9.6	14.7	61.0	7.6			
Forestry		20.0		30.0	50.0			
Industrial	6.3	10.8	11.6	35.9	26.2	9.1	0.0	
Lawn and Garden			20.0	70.0	10.0			
Light Commercial				100.0				
Marine (<37 kW)			1.3	92.0	1.7	5.1		
Other (used vehicle propulsion engines)		100.0						
Power Generation Drives	22.9	1.4		66.7	0.4	8.5		
Power Generation Sets	37.4	10.5	0.1	36.3	14.9	0.9		
All Non-road Diesel Engines/Equipment	8.8	11.2	11.0	47.1	16.8	5.1	0.0	

(a) Implementation dates for US emission standards are as follows: Tier 1 (1996-2000), Tier 2 (2001-2005), Tier 3 92006-2008), Tier 4i (2008) and Tier 4 final (2011-2015).
(b) Only marine engines <37 kW were included in the study, given that such engines are covered specifically by US non-road diesel emission standards. (The US regulate marine diesel engines >37 kW under marine specific US-EPA rulemakings.)

Table 28: Number of non-road diesel engines/equipment sold into Australia during 2008 which are *certified* to an international non-road diesel emission standard

Segment	US Tier 1 / EU Stage I	US Tier 2 / EU Stage II	US Tier 3 / Stage IIIa	US Tier 4i	Total Certified
	Number of Engines/Equipment within each Market Segment which are *Certified*				
Agriculture	107	1,921	6	-	2,034
Forestry	-	9	15	-	24
Industrial	466	7,163	4,594	2,289	14,511
Lawn and Garden	-	-	-	-	-
Light Commercial	-	-	-	-	-
Marine (<37 kW)	1	426			428
Other (used vehicle propulsion engines)	-	-	-	-	-
Power Generation Drives	-	1,394	2	210	1,606
Power Generation Sets	3	1,311	531	-	1,845
All Non-road Diesel Engines/Equipment	576	12,225	5,148	2,499	20,448

Approximately 36% of all diesel engines sold in Australia were reported by industry as being certified to any particular emissions standard (**Table 28**). Engines/equipment compliant with more stringent standards were found to be more likely to be certified (87% of US Tier 4 interim compliant engines were given as being certified, compared to 55% of US Tier 3 compliant engines, 46% of US Tier 2 compliant engines and 9% of US Tier 1 compliant engines).

More detailed emission performance information is given by end use application / equipment type in **Appendix E**. Observations in respect of such information is provided by market sector in the subsections below.

Industrial (Construction, Mining) Equipment

About 11% of industry equipment/engines were estimated to be non-compliant with a further 12% being Tier 1 compliant. A significant proportion of industrial engines/equipment are estimated to be either Tier 2 (36%) or Tier 3 (26%) compliant. 9% of industrial engines/equipment were reported by industry to comply with Tier 4 standards.

The emission performance status of heavy industrial (construction, mining) engines and equipment is given in **Table 29**.

Table 29: Percentage of industrial (construction, mining) equipment complaint / non-compliant with an international non-road diesel emission standard

Heavy Industry Applications	% of Engines/Equipment which are Compliant/Non-compliant				
	US Tier 1 / EU Stage I	US Tier 2 / EU Stage II	US Tier 3 / Stage IIIa	US Tier 4i	Non-compliant
Construction & Mining Engines	3	68	8	10	3
Construction & Mining Equipment	0	21	52	13	3
Cranes and lifting equipment	97	-	-	-	3
Other Industrial Engines	-	67	7	5	16
Industrial Pumps	4	14	7	13	55

The compliance status of heavy industrial (construction, mining) equipment is noted to vary significantly from the status of loose engines sold for heavy industrial (construction, mining) applications. Whereas heavy industrial equipment is dominated by Tier 3 compliant units, the heavy industrial engines are predominantly Tier 2 compliant. This difference appears to reflect earlier observations made in respect of the divergent energy rating profiles of engines and equipment (**Section 5.4.5**).

A significant portion of industrial pumps are reported to be non-compliant (55%), with the remainder generally being compliant with Tier 2 or higher standards.

Power Generation

Emission compliance information is not available for a notable portion of power generation drives (23%) and gen sets (37%). Based on compliance information for the remaining engines the following observations were made:

- Classifiable power generation drives are mainly Tier 2 / Stage II compliant (67%), with the remainder being mainly Tier 4i compliant (9%). Only 1.4% of power generation drives were identified as being non-compliant.In comparison, 11% of power gen sets were reported to be non-compliant with 36% Tier 2 compliant and 15% Tier 3 compliant. Only 1% of gen sets were reported to be Tier 4i compliant.

Light Commercial and General Industrial

Light commercial and general industrial equipment such as forklifts, welders and air compressors are frequently used indoors. Due to occupational health concerns and regulations new industrial equipment sales tend to be dominated by cleaner technologies (e.g. battery-electric forklifts). Based on this observation, and taking available product data into account, it was assumed that new light commercial and general industrial equipment would as a minimum be compliant with US Tier 2 emission standards. Used equipment was assumed to be non-compliant.

Agricultural Equipment

The emission performance status of agricultural engines/equipment largely reflects industry provided information for agricultural pumps and irrigation and estimates for agricultural tractors.

Taking into account new and used agricultural tractor sales, 1% of tractors were concluded to be non-compliant, 20% Tier 1 compliant, almost 70% Tier 2 compliant and 10% Tier 3 compliant.

About 40% of agricultural pumps were found to be non-compliant, 3% Tier 1 compliant, 51% Tier 2 compliant and 3% Tier 3 compliant, with the remaining 5% unknown. It is anticipated that the unknown portion are likely to comprise non-compliant or, at best, Tier 1 compliant pumps.

Marine

Small (less than 37 kW) marine engines are primarily given as being Tier 2 compliant (92%), with 7% of engines being Tier 3 or Tier 4i compliant. The remaining ~1% of engines are Tier 1 or equivalent compliant.

Lawn and Garden

Emission performance statistics could not be generated for the diesel-powered lawn and garden segment due to the unavailability of market share information. Based on discussions with industry suppliers, and taking available product data into account, it was assumed that 20% of ride on / tractor mowers would comply with Tier 1, 70% with Tier 2 and 10% with Tier 3.

Forestry

Logging (forestry) equipment includes chainsaws, shredders, skidders, fellers, bunchers and delimbers. According to PAE (2005) only skidders and fellers/bunchers/delimbers are diesel powered, with log skidders representing the larger source of emissions[(51)].

Given the relatively small number of in-service diesel logging equipment (estimated by PAE to be ~4,200), the low contribution of such emissions to overal non-road diesel equipment

51 PAE (2005). Management Options for Non-road Engine Emissions in Urban Areas, Report compiled by Pacific Air and Environment on behalf of the Department of the Environment and Heritage, November 2005.

emissions (0.4%) and the fact that such emissions are non-urban, logging equipment was not considered a critical component of the current study. The acquisition of sales and emissions performance information was therefore limited to log skidders.

PAE (2005) reported that all forestry equipment is imported, generally from North America, Europe and Japan and that the majority of engines are expected to be US Tier 2 compliant. Based on the assessment of the compliance status of the 30 log skidders sold in 2008 it is evident that 20% are non-compliant, 30% are Tier 2 compliant and 50% are Tier 3 compliant.

Compliance Status By Engine Rating

The compliance status of loose diesel engines (the largest market grouping) was assessed by engine rating (**Figure 17**). Small engines (less than 10 kW) are mainly non-compliant or Tier 2 / Stage II compliant. The percentage of Tier 3 and Tier 4i compliant engines increases with higher power ratings.

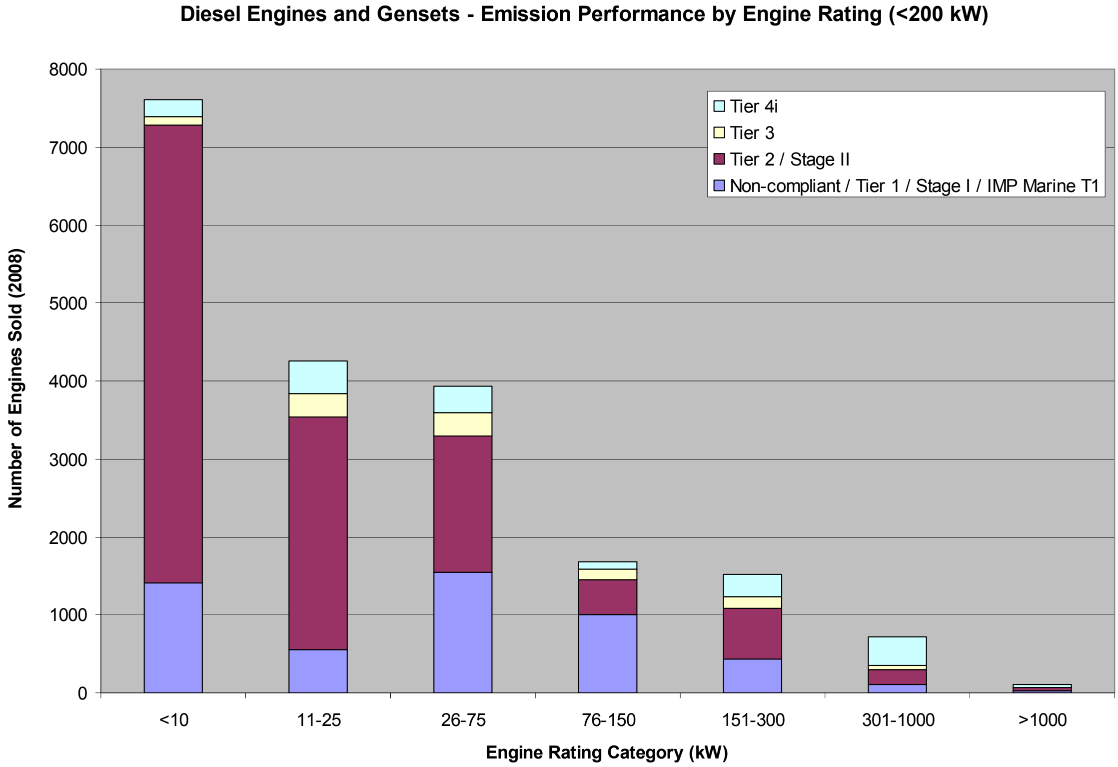

Figure 17: Emissions performance status of non-road diesel engines sold into Australia during 2008 by engine rating

5.6 Fuel Composition for Non-road Applications

The extent and composition of diesel exhaust emissions is not only dependent on the emission performance of engines and equipment but also on operational factors and fuel composition.

By example, increases in the cetane index (indicative of fuel autoignitability) and reductions in the aromatic content of fuel results in lower emissions of NO_x, HC, CO and PM. Lowering the sulfur content of fuel reduces both the SO_2 and particulate sulfur emissions. Fuel sulfur content not only affects emissions but also engine wear and deposit formation. Fuel sulfur also affects the effectiveness of emission control equipment, especially the efficiency of catalysts.

Given the significant influence fuel composition has on engine design, operation and emissions, it is not surprising that the management of fuel quality is being incorporated into diesel equipment emission management measures, e.g. US Clean Diesel Rule passed in 2004.

In Australia, Commonwealth Fuel Quality Standards mandate fuel quality for petrol, automotive diesel, biodiesel and autogas and a fuel quality information standard applies to the supply of petrol with up to 10% ethanol. In the US specific fuels standards apply to off-road (non-road) diesel engines.

5.6.1 Automotive Diesel in Australia

Diesel, or Automotive diesel oil (ADO), is a product derived from the distillation of crude oil and comprises one of the middle distillates.

The fuel standard for diesel holds relevance given that non-road engines and equipment may be powered by fuels bought from the major fuel retailers which therefore comply with the national fuel standards.

The *Fuel Standard (Automotive Diesel) Determination 2001*, incorporating the *Fuel Standard (Automotive Diesel) Amendment Determination 2009 (No. 1)*, specifies that diesel must comply with the following requirements:

Substance	Amount	Date
Sulfur	500 mg/kg	31 December 2002
Sulfur	50 mg/kg	1 January 2006
Sulfur	10 mg/kg	1 January 2009
Ash	0.01% (m/m)	1 January 2002
PAH (Polycyclic aromatic hydrocarbons)	11% mass by mass	1 January 2006
Biodiesel	5.0% volume by volume	1 March 2009

The sulfur content of diesel has been regulated down from 500 ppm to 50 ppm, and most recently to 10 ppm. Following extensive stakeholder consultation amendments have been made to the Fuel Standard (Automotive Diesel) Determination 2001 to allow up to five per cent biodiesel in diesel fuel without a labelling requirement from 1 March 2009.

There are circumstances where the use of blends with more than five per cent biodiesel, such as 80 per cent diesel and 20 per cent biodiesel or B20, are given as being appropriate; for example in commercial truck or bus fleets and mining vehicles. It is indicated that, in the short-term, the supply of higher blends will be managed via an approvals process. Labelling will be a condition of any approval for supply of blends over five per cent, with the vehicle or fleet owner to make sure their vehicles are able to operate on the higher percentage level blend.

Some non-road engines and equipment may be operated using fuels that do not meet the Fuel Standard (Automotive Diesel) Determination 2001 (as amended). No information could however be obtained on the use of such fuels. Based on consultations with people working in the Australian mining industry, PAE (2005) concluded that black diesel (off-spec fuel) is not used in mining fleet as it would be damaging to the engine systems[52]. Most large facilities such as mine and industrial sites have on-site fuel storage for vehicle fleet

52 PAE (2005). Management Options for Non-road Engine Emissions in Urban Areas, Report compiled by Pacific Air and Environment on behalf of the Department of the Environment and Heritage, November 2005.

refuelling, with fuel being sourced from major petrochemical suppliers (and therefore compliant with fuel standards). The potential exists however that some non-road diesel engines are operated using fuels that do not meet the fuel standards.

5.6.2 Recycled Used Oil

The *Product Stewardship for Oil (PSO) Program* was introduced in 2001 by the Australian Government to provide incentives to increase used oil recycling. The arrangements comprise a levy-benefit system, where a 5.449 cent per litre levy on new oil, funds benefit payments to used oil recyclers. The Program, administered by the Department of the Environment, Water, Heritage and the Arts (DEWHA), aims to encourage the environmentally sustainable management and re-refining of used oil and its re-use. These arrangements provide incentives to increase used oil recycling in the Australian community(53).

According to AATSE (2004) all re-refining processes produce a diesel fraction but only Nationwide in NSW and Environmental Oil in Victoria sell product specifically as diesel fuel for transport and stationary diesel engines(54). Other producers sell product specifically as fuel oil for general burning applications (including high and low grade industrial burning oils).

Information on the volume of recycled products produced from used oil can be obtained by considering the PSO benefit payment information. This information is however indicative only of used oil flows since there can be changes in the inventory level of used oil in storage. The volume of used oil derived product sold, and the proportion of the total recycled product sold through time for diesel fuel, is illustrated in **Figure 18**. A dramatic reduction in the sale of diesel fuel oil (25 million litres in 2001-2, but only 2.9 million litres in 2006-7) is evident. This fall in diesel sales is given by ACIL Tasman (2008) as relating to changes in the *Fuel Quality Standards Regulations 2001*(55).

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53 Information obtained from the DEWHA website, www.oilrecycling.gov.au/program/.

54 AATSE, 2004 Independent Review of the Transitional Assistance Element of the Product Stewardship for Oil (PSO) Program. Australian Academy of Technological Sciences and Engineering

55 ACIL Tasman (2009). Used oil management option study, Final Report, Part A: Report on the Western Australian used oil market, Prepared for the Waste Authority, November 2008.

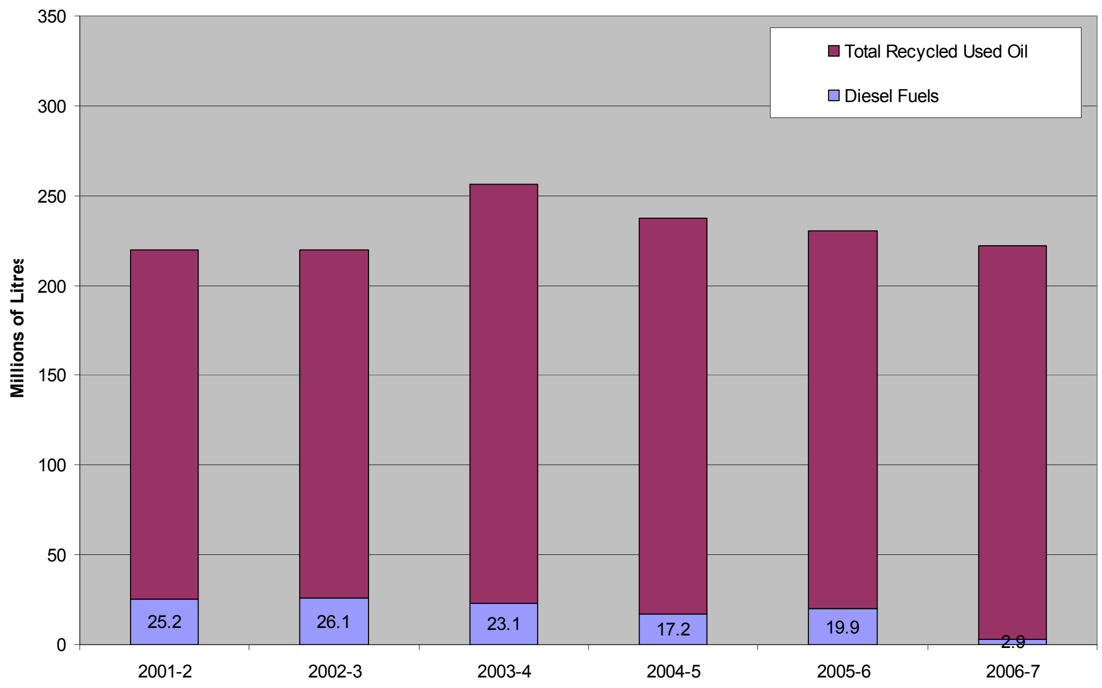

Figure 18: Volume of used oil products based on Product Stewardship for Oil benefits claimed, with the proportion of diesel fuel indicated.

Whereas the mandatory diesel specification for sulfur has been reduced from 5,000 ppm to 500 ppm, to 50 ppm and more recently (January 2009) to 10 ppm, the typical sulfur content of re-refined diesel is in the range of 1,000 to 9,000 ppm. The excise rate for diesel with greater than 50 ppm sulfur increased in 2003 as a result of the Diesel Sulfur Excise Differential Program.

It is anticipated that the increasingly stringent sulfur specifications and raised excise have reduced the market for used oil derived diesel fuels. Fuel uses such as stationary engines, non-road vehicles, marine propulsion engines, and construction and mining equipment used in remote environments have been highlighted as possibly sustaining the market for recycled product with sulfur levels greater than 50 ppm[56][57].

If high sulfur content re-refined diesel fuel remains commercially available for non-road applications, it will have a significant negative impact if used for engines equipped with after treatment, and on engines using oils which are not developed for elevated fuel sulfur operation.

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56 PAE (2005). Management Options for Non-road Engine Emissions in Urban Areas, Report compiled by Pacific Air and Environment on behalf of the Department of the Environment and Heritage, November 2005.
57 AATSE, 2004 Independent Review of the Transitional Assistance Element of the Product Stewardship for Oil (PSO) Program. Australian Academy of Technological Sciences and Engineering

5.6.3 Use of Oil Burn Systems

Oil burn systems in large diesel engines inject small quantities of used oil from the engine into the diesel just prior to it being burnt in the combustion chamber. Oil burn systems are designed for use in machines in demanding operating conditions. In Australia, oil burn systems can either be supplied as optional extras or fitted as part of the machinery when purchased, such as within large diesel engines operated at mine sites. Alternatively, they can be retrofitted to diesel engines, including stationary power generators and diesel trucks.

Oil burn systems inject engine sump oil into the fuel line, where it is mixed with diesel fuel and burnt in the engine. A typical injection rate is 0.5%, although some systems allow the operator to adjust the oil dosage rate higher. To replace the oil burnt, the engine is 'topped up' with new oil whenever the vehicle is refuelled with diesel. Oil burn systems are claimed to improve the overall engine life by improving the quality of the engine oil between oil changes and increasing the interval between oil changes. In addition to which it is claimed that this in turn increases the availability and productivity of equipment and thus assists in reducing the waste oil stream[(58)].

The Department of the Environment, Water, Heritage and the Arts (DEWHA) recognised that the use of oil burn systems in diesel vehicles can potentially breach Section 20 of the *Fuel Quality Standards Act 2000* (the Act) if the addition of oil to the diesel within the engine results in the diesel not complying with the *Fuel Standard (Automotive Diesel) Determination 2001*. DEWHA released a discussion paper in February 2008 to facilitate consultation with stakeholders on this issue. The management of oil burn systems under the Act is still under consideration with no decision made at the time of compiling the current report. The ADRs have general provisions that require any components on vehicles that assist the engine under normal conditions of operation and use. Such ADRs do not however cover non-road vehicles and equipment, such as that used in mining and construction.)

5.7 Summary of Findings

Industry Structure

Diesel engines are not manufactured locally but rather imported into Australia, either as loose diesel engines or already incorporated into equipment.

Engine and equipment sales are typically dominated by a small number of leading brands with the remaining small proportion of the market being shared by a wide range of alternative brands.

The most pertinent industry associations are the recently constituted Australian Diesel Engine Distributors Association (ADEDA); the Construction and Mining Equipment Industry Group (CMEIG); and the Tractor and Machinery Association of Australia (TMA).

Engine/Equipment Imports

About 73,900 non-road diesel engines/equipment were imported into Australia during 2008, comprising: loose diesel engines and power generation sets (40%), agricultural equipment

58 DEWHA (2008). Fuel Quality Standards Acto 2000, Management of Diesel Oil Burn Systems, Discussion Paper, Australian Department of Environment, Water, Heritage and Arts, February 2008.

(26%), and heavy industrial, construction and mining equipment (24%). The remaining 10% of imports included other industrial equipment (airport ground service equipment, cranes, forklifts), light commercial equipment (compressors, welders, pressure washers) and lawn ride on and tractor mowers.

Used diesel engines were estimated to account for less than 3% of total imports, with such engines being dominated by used vehicle propulsion engines (70%) and heavy industrial (construction, mining) equipment (20%); with agricultural tractors comprising a smaller number (6%) of used equipment imports[59] .

Japan, the US and China are the largest sources of non-road diesel imports, together accounting for 67% of total imports across these equipment categories. Germany, Italy, the UK, Korea, Sweden, France and India representing more minor sources of total imports.

National Engine/Equipment Sales

Non-road diesel engine/equipment sales were estimated to be 56,233 for 2008 (i.e. 76% of imports). This difference between sales numbers and imports is mainly due to the lower sales figures for agricultural tractors (~60% of imports) and loose diesel engines and gen sets (76% of imports). Engine and gen set exports are expected to account for the latter[60]. The reason for the difference in imports and local sales figures for agricultural tractors is unclear. Given industry confidence that sales figures are reasonably complete, it is possible that import statistics do not accurately reflect the influx of actual working agricultural tractors.

The estimated annual sales of non-road diesel engine/equipment in 2008 (56,233) represents about 9% of the extrapolated in-service non-road diesel population for this year (~620,000). This percentage is comparable to that documented for the United States (10%)

Market Segmentation of Engine/Equipment Sales

Broad industrial applications (including industrial, commercial, construction and mining applications) are estimated to account for 50% of non-road diesel engine/equipment sales. Agricultural applications represent the second largest use (30%), followed by Power Generation across markets (11%). Together these three categories account for over 90% of non-road diesel engines/equipment sales. More minor applications include Lawn and Garden (3.4%), Light Commercial (1.8%), Marine Propulsion (0.9%) and Forestry (0.1%).

Market Share by Engine Rating

Non-road diesel engines differ from on-road engines in that they range widely in engine size and power ratings.

Small engines (less than 19 kW) make up almost 30% of the total market, with 3% of engines sold falling within the greater than 560 kW range. These engine categories are

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59 Used vehicle propulsion engines include on- and off-road engines. Engines initially manufactured abroad for the on-road market may however be applied within various non-road applications.

60 About 13,400 non-road diesel engines were reported to be exported from Australia during 2008. Given that no engines are locally manufactured, these engines represent units previously imported.

subject to non-road diesel emission regulation in the the United States but are excluded from such regulations by the EU.

Agricultural pumps and irrigation applications are dominated by small engines (76% less than 8 kW; 80% less than 19 kW). The average power rating of agricultural tractors sold is of the order of 60 kW, with about 20% of tractors being smaller than 19 kW. About 86% of heavy industrial (construction, mining) equipment falls in the 19 kW to 560 kW range, with only 6% less than 19 kW.

Trends in Non-road Diesel Engine Sales

The extent of non-road diesel engine/equipment sales is projected to have grown over the last decade, with the post 2005 reduction in loose diesel engine sales being off-set by the increase in agricultural tractor sales.

Non-road diesel engine/equipment sales data by state was available for 76% of total numbers sold. The bulk of the sales are within Queensland (30%), NSW (25%), Victoria (21%) and Western Australia (14%).

Emission Performance Status

Overall the emission compliance status of about 90% of inventoried non-road diesel engine/equipment sold into the Australian market during 2008 were either established based on industry data or estimated. The compliance status of about 10% of engines/equipment could not be established, comprising primarily of power generation drives and sets and agricultural equipment (other than agricultural tractors).

The emission performance status of engines/equipment was assessed based on whether they complied with international emissions limits such as those issued by the US and EU for non-road diesel engines. In the case of engines/equipment given as complying with a specific standard, it was determined whether certification of compliance had been achieved[(61)].

The overall compliance status of the non-road diesel engines/equipment sold into the Australian market during 2008 was characterised as follows: unknown (8.8%), non-compliant (11.2%), US Tier 1 / EU Stage I compliant (11%), US Tier 2 / EU Stage II compliant (47.1%), US Tier 3 / EU Stage IIIa compliance (16.8%), and US Tier 4 interim (5.1%). Engines/equipment compliant with more stringent standard were found to be more likely to be certified.

Fuel Composition

The extent and composition of diesel exhaust emissions is not only dependent on the emission performance of engines and equipment but also on operational factors and fuel composition. In Australia the mandatory automotive diesel oil (ADO) specification for sulfur has been reduced from 5,000 ppm to 500 ppm, to 50 ppm and more recently (January 2009)

61 Certification comprises the engine/equipment having the necessary documentation, certified by the competent authority, that the engine/equipment supplied meets the required specifications.

to 10 ppm. The typical sulfur content of re-refined diesel oil may however be significantly higher.

Although it is speculated that off-spec diesel is not widely used by large mining and industrial fleets, the potential exists that some non-road diesel engine/equipment applications are operated using such fuel.

It has also been postulated that the increasingly stringent sulfur specifications and raised excise have reduced the road transport diesel fuel market for used oil derived diesel fuels. Fuel uses such as stationary engines, non-road vehicles, marine propulsion engines, and construction and mining equipment used in remote environments have been highlighted as possibly sustaining the market for recycled product with sulfur levels greater than 50 ppm.

If high sulfur content diesel fuel remains commercially available for non-road applications, it will have a significant negative impact if used for engines equipped with after treatment, and on engines using oils which are not developed for elevated fuel sulfur operation.

6 Australian Market for Cleaner Non-road Diesel Engines

A survey of the attitudes of major users of non-road diesel equipment users towards the uptake of cleaner non-road diesel engines and equipment was undertaken to inform the current study. An overview of the survey method is given in Section 6.2. The results of the survey are presented in the following subsections:

- Knowledge of and attitude towards cleaner equipment alternatives (**Section 6.2**);
- Purchasing behaviours, specifically inclusion or absence of emission performance requirements from purchasing policies (**Section 6.3**);
- Any measures previously undertaken or being considered to reduce emissions from non-road diesel equipment use (**Section 6.4**);
- Facility, company and/or sector specific trends affecting future non-road diesel engine purchases (**Section 6.5**);
- Willingness to engage in voluntary schemes to reduce emissions from non-road diesel equipment (**Section 6.6**);
- Attitudes towards the different options for government in regulating emissions from non-road diesel equipment (**Section 6.7**); and
- Obervations made in respect of differences in knowledge and attitude across industry types (**Section 6.8**).

6.1 Survey of Large Non-road Diesel Engine Users

A project-specific survey was designed comprising sets of questions aimed at addressing the goals listed above. These questions were generally presented as yes/no answers with space provided for the respondents to add additional notes and comments.

A cross section of firms were identified for inclusion in the survey, with the aim of providing a reasonable degree of coverage across industries with significant non-road diesel applications. In total 32 firms in the construction, manufacturing, ports, airports, mining, and waste sectors were invited to respond to the survey. The environmental managers from these firms were contacted through an e-mail containing the survey, with subsequent telephonic and email correspondence.

Of the 32 firms surveyed, 18 responses were received, including 13 completed surveys. Four firms declined the invitation to respond to the survey. The companies having completed surveys came from the following industry sectors: construction (4), mining (2), ports (2), airports (1), waste (1), and manufacturing (3).

The firms targeted in each industry sector are listed and an example of the survey format given in **Appendix F**, with results from the survey documented in **Appendix G** and discussed in subsequent subsections.

6.2 Knowledge of Cleaner Equipment Alternatives

Most companies are not familiar with non-road diesel certification levels.

The minority of companies with some knowledge of certification levels indicated that this knowledge was based on information provided by their non-road diesel equipment suppliers about the air emissions performance of the equipment they were purchasing.

Only about 40% of companies indicated that the obtained some information about emission performance from their non-road diesel engine/equipment suppliers. Smaller suppliers were noted to be less forthcoming with information compared to larger equipment suppliers.

6.3 Non-road Diesel Equipment Purchasing Behaviours

Purchasing behaviours were assessed, specifically the inclusion or absence of emission performance requirements from purchasing policies.

Over half of all surveyed companies indicated that air emissions performance is currently a consideration when purchasing or leasing non-road diesel equipment.

The two main reasons given for the remaining companies not including air emissions performance as a component in their purchasing decision making included:

- A lack of information on the emission performance of equipment.
- Non-road diesel equipment used at site belongs to external service providers. Although environmental performance criteria are included in the criteria for selecting such service providers, such criteria is fairly general and does not typically include emissions performance requirements for non-road diesel equipment used.

Despite over half of companies indicating that emissions performance is taken into account in purchasing non-road diesel equipment, it is noted that few companies (3 of 13) have documented policies governing the purchase of low emission non-road diesel equipment. Furthermore, the formal purchasing policies where they exist are generic environmental purchasing policies and do not relate specifically to non-road diesel equipment.

6.4 Management of Non-road Diesel Emissions

Companies were surveyed in regard to measures previously undertaken or being considered to reduce emissions from non-road diesel equipment use.

Although the majority of companies indicated that they have air quality management plans and are implementing air emission mitigation measures, the focus of these plans and actions is primary sources of air emission. Non-road diesel equipment emissions are perceived by most companies to be a relatively minor source and therefore a lower priority.

Despite mitigation measures for non-road diesel equipment not being included in air quality management plans, and such emissions being considered as minor, it is notable that most companies have undertaken specific actions which address air emissions from non-road diesel equipment. The majority of such actions focus on fuel use and maintenance practices, where other benefits such as improved fuel efficiency, productivity and possibly safety considerations are likely to be major drivers.

Only one company indicated that it had used the choice of engine and supplier as a method of managing air emissions from non-road diesel equipment.

6.5 Trends in Future Non-road Diesel Purchases

Large scale users of non-road diesel equipment, such as mines, tend to replace their equipment on a cyclical basis based on equipment age and performance.

Whereas the majority of companies surveyed indicated that equipment was replaced on an as-needs basis, only one company indicated it has a larger project underway to replace its non-road diesel equipment with equivalent electric equipment.

6.6 Willingness to Engage in Voluntary Measures

Almost half of the companies surveyed have participated in one or more voluntary schemes for the reduction of air emissions. Examples of such programs were given as including improvement initiatives incorporated into Pollution Reduction Programs, low sulfur diesel schemes, Greenhouse Challenge Plus, and contributions to the development of regulations.

Sixty percent of the companies surveyed indicated that they would be willing to participate in a voluntary scheme for the reduction of air emissions from non-road diesel equipment. Most of these companies indicated that clear incentives would be required for participation such as financial incentives and improved market reputation. One company highlighted the need for the voluntary scheme to be endorsed and promoted by significant government departments.

Most of the remaining companies were not opposed to cleaner non-road diesel technologies but were of the view that either mandatory measures or financial incentives should be implemented in place of voluntary measures.

6.7 Preferred Measures for Implementing Cleaner Non-road Diesel Alternatives

The majority of companies (12 out of 13) surveyed were open to cleaner non-road diesel alternatives.

About half of these companies favoured a combination of guidelines, improved information and financial incentives as the most effective measures for realising reductions in air emissions from non-road diesel engines and equipment.

The use of mandatory measures to address air emissions from non-road diesel was viewed by 30% of companies as a potentially effective means, either in isolation or in addition to improved information and financial incentives. Mandatory regulation was favoured as a means of creating a level playing field for all participants in an industry.

Some companies emphasised financial incentives as being the most effective and acceptable method implementable to address non-road diesel air emissions.

6.8 Differences in Knowledge and Action across Industry Types

Some observations made in respect of differences between industry types are presented. Given the limited number of industries who participated in the study, these observations should be interpreted as preliminary.

Major mining companies, ports and some construction companies appear more likely to be aware of cleaner non-road diesel alternatives, and take actions to reduce emissions from in-service non-road diesel equipment.

A lower level of knowledge and action was evident among manufacturing industries and airports. This may be due to non-road diesel equipment used at their sites being owned and/or operated by external equipment fleet operators.

6.9 Summary of Findings

Most companies are not familiar with non-road diesel certification levels. In cases where knowledge is held, it is mainly based on information provided by non-road diesel equipment suppliers.

Although the purchasing behaviours of some companies include non-road diesel emissions performance considerations, none of the companies surveyed had specific documented policies governing the purchase of low emission non-road diesel equipment. Furthermore, the control of non-road diesel engines/equipment are typically not included in the air quality management plans of companies.

Some companies who are large scale non-road diesel equipment users have undertaken specific actions to address air emissions from such equipment (despite not including these sources formally in their air quality management plans). These actions tend to focus on fuel use and maintenance practices, where other benefits such as improved fuel efficiency, productivity and possibly safety considerations are likely to be major drivers.

Within industrial applications where equipment operates indoors, the need to reduce occupational exposure potentials has been a driver in the selection of cleaner equipment (e.g. battery-electric forklifts). The choice of engine and supplier appears seldomly to be used as a method of managing air emissions from non-road diesel equipment in the absence of other significant drivers.

The main reasons identified for non-road diesel equipment emissions not being subject to further controls by companies are as follows:

- Non-road diesel equipment are not regulated and represent a minor source of air emissions compared to major point and fugitive sources.
- Lack of information on the emissions performance of non-road diesel equipment.
- Lack of best practice guidance on the emissions performance of non-road diesel equipment.

- Absence of financial incentives to control non-road diesel equipment emissions or move towards cleaner alternatives.

Companies generally seem open to cleaner non-road diesel alternatives. In terms of the most effective and acceptable methods of realising reductions in air emissions from non-road diesel equipment, companies tended to support either a combination of guidelines, improved information and financial incentives, or the use of mandatory measures, either in isolation or in addition to improved information and financial incentives.

7 Review of Emission Management Measures

A review of measures implemented locally and abroad to reduce atmospheric emissions from non-road diesel engines and equipment is undertaken in this Section. International measures implemented to reducing emissions from new non-road diesel engines and equipment are reviewed in **Section 7.1**. Although the study primarily focuses on measures for new equipment, the effectiveness of diesel retrofit programs for in-service non-road engines are briefly considered in **Section 7.2**.

A summary of the targetted products and emission management options for potential consideration within the Australian context is given in **Section 7.3**.

7.1 Review of Measures for New Non-road Diesel Engines and Targeted Products

In the review of international and local (as applicable) measures for reducing emissions from new non-road diesel engines and equipment, attention was paid to voluntary and mandatory measures implemented in North America, Europe and Asia.

7.1.1 United States

The main approach in the United States to the management of emissions from new non-road diesel engines and equipment comprises:

- Emission standards for non-road diesel engines, first introduced as Tier 1 standards for 1996 models;
- Fuel quality specifications (and alignment of non-road diesel quality and emission standards from 2004 onwards); and
- The Blue Skies Series Engines program – a US-EPA program of voluntary standards designed to encourage early introduction of ultra-low emission engines through offering incentives.

Emission Standards and Fuel Specifications

A detailed overview of US non-road diesel emission standards, and the categories of engines and equipment to which such standards apply, was given in **Section 4.** These standards are part of the US-EPA's *National Clean Diesel Campaign* (NCDC), a comprehensive initiative to reduce pollution from diesel engines throughout the country, including vehicles on highways, city streets, construction sites and ports. The NCDC includes regulatory programs to address new engines and innovative programs to address diesel engines already in use.

Fuel quality has been increasingly regulated by the US-EPA under the authority of the Clean Air Act. For diesel, sulfur content is the most stringently regulated fuel property on environmental grounds. Historically the sulfur content in diesel fuels for highway and non-road vehicles was limited to 0.5% (wt.). Diesel Fuels have since been regulated to 500 ppm in June 2007 for non-road, locomotive and marine fuels, and are scheduled to be reduced to 15 ppm (termed ultra low sulfur diesel, ULSD), effective June 2010 for non-road fuel and

June 2012 for locomotive and marine fuels. ULSD has been legislated for non-road engines to enable advanced emission control system to ensure compliance with the Tier 4 non-road emission standards.

Blue Sky Series

Blue Sky Series engines are required to be typically about 40% cleaner and to retain their engines at Blue Sky Series levels (**Table 30**) throughout their useful life. These emission levels are typically achieved by adding aftertreatment technologies or by using alternative fuels such as natural gas.

Table 30: US-EPA Voluntary Blue Sky Series Emission Standards for Non-road Diesel Engines

Rated Power (kW)	NMHC+NOx (g/kWh)	PM (g/kWh)
kW < 8	4.6	0.48
8 ≤ kW <19	4.5	0.48
19 ≤ kW <37	4.5	0.36
37 ≤ kW < 75	4.7	0.24
75 ≤ kW <130	4.0	0.18
130 ≤ kW < 560	4.0	0.12
kW ≥ 560	3.8	0.12

The Blue Sky Series Engines program is scheduled for review in 2010-11. No information could be obtained on the percentages of engines which comply with these voluntary emissions standards, on which basis to assess the potential success or significance of the program.

Environmental Cost and Benefit

At the time of promulgating the 1998 rule, the costs of meeting the emission standards were given as adding under 1% to the purchase price of typical new non-road diesel equipment, despite the price increase being 2-3% for some equipment types. The program was expected to cost about US$600 per ton of NO_x reduced.

For the US Clean Diesel Rule passed in 2004, the US-EPA estimates that the benefits (savings, estimated at approximately US$80 billion/year) achievable will outweigh costs (estimated at US$2 billion/year) by a ratio of 40 to 1 by 2030(62). The estimated costs for added emission controls for the majority of equipment was estimated at 1-3% as a fraction of the total equipment price.

62 US-EPA (2004). Final Regulatory Analysis: Control of Emissions from Non-road Diesel Engines, EPA-420-R-04-007, May 2004.

7.1.2 Canada

The main approaches which have been used in Canada for the management of emissions from new non-road diesel engines and equipment have included:

- Pre-regulation Memorandum of Understanding (MoU);
- Emission standards for non-road diesel engines (as documented in **Section 4**); and
- Fuel quality specifications.

Before the promulgation of regulations for non-road engines, Environment Canada signed MoUs with 13 engine manufacturers in 2000. Under the terms of these MoUs, manufacturers agreed to supply non-road diesel engines designed to meet US-EPA Tier 1 standards.

Emission Standards

Canada currently regulates non-road diesel engines under the Off-Road Compression-Ignition Engine Emission Regulations which were promulgated in February 2005. These regulations introduced emission standards for model year 2006 and later diesel engines used in non-road applications such as those typically found in construction, mining, farming and forestry machines. These regulations encompass the US-EPA Tier 2 and Tier 3 standards. Alignment with US Tier 4 rules is anticipated later through a separate process.

Given that the Canadian emission standards are aligned with those of the US, these standards were not documented in **Section 4**. It is however worthwhile indicating some important differences in the Canadian standards. The Canadian regulations apply to non-road engines of model year 2006 and later. Compliance in Canada with US-EPA Tier 1 requirements was through a voluntary agreement signing in 2000. Compliance in Canada with US-EPA Tier 2 requirements was not mandatory until the 2006 model year. The Canadian Off-Road (non-road) Compression-Ignition Engine Emission Regulations also do not include an optional averaging, banking and trading program as do the US-EPA regulations.

Emissions from engines used exclusively in underground mining equipment in Canada fall under provincial jurisdiction. While emissions from these engines are not directly regulated, provincial regulations exist for ventilation rates in mines where these engines are used. Canadian Standards Association (CSA) standards have been established that describe the technical requirements and procedures necessary for the design, performance, and testing of new or unused non-rail-bound, diesel-powered, self-propelled machines in underground mines.

Fuel Specifications

Diesel fuel is regulated in Canada through the *Sulfur in Diesel Fuel Regulations* and the *Fuels Information Regulations*, No. 1. The *Sulfur in Diesel Fuel Regulations* specify sulfur limits for on-road and non-road diesel fuels sold in Canada that are either produced domestically or imported. The first rule, published in July 2002, focused on on-road diesel fuels. Amendments published in October 2005 added biodiesel, non-road and locomotive and marine diesel fuels to the regulations. The *Fuels Information Regulations, No. 1* require that sulfur content and additive use be reported for all fuels.

Permissible sulfur concentrations in fuels in Canada are aligned with those in the US. Sulfur in non-road diesel fuel was reduced to less than 500 ppm in 2007 and will be reduced to less than 15 ppm in 2010.

Diesel fuel quality specifications in Canada are the responsibility of the Middle Distillates Committee of the Canadian General Standards Board. This Committee maintains a number of standards for diesel fuel used in different applications, including: specifications for on-road applications; CAN/CGSB-3.6 *Regular Sulfur Diesel Fuel* which is limited to non-road applications; and CAN/CGSB-3.16 *Mining Diesel Fuel* for use in underground mining applications.

7.1.3 Europe

The main approach adopted by the EU for the management of emissions from new non-road diesel engines and equipment comprises mandatory emission standards for non-road engines introduced in 1997, and diesel fuel quality specifications.

Emission Standards and Fuel Quality Specification

A detailed overview of EU non-road mobile machinery directive (97/68/EC) emission standards, and the categories of engines and equipment to which such standards apply, was given in **Section 4.**

Significant differences in the applicability of the EU emission standards, compared to that of the US, include: (i) exclusion of smaller and larger engines, i.e. engines less than 19 kW and greater than 560 kW[(63)], (ii) inclusion of rail traction engines, and (iii) more complex definition of marine engines based on vessel length, engine size, vessel uses and areas of application (compares to the US including marine engines less than 37 kW). The EU directive also extends to the inclusion of certain categories of non-road spark ignition engines.

The quality of automotive fuels in the European Union is specified by standards developed by the European Standards Organization (CEN). The first set of standards for automotive fuels, ratified by CEN on 16 March 1993, became mandatory in all Member States by September 1993. Diesel fuel is covered by the standard EN 590. The standards are periodically updated to reflect changes in specifications, including mandatory reductions in sulfur content.

Mandatory environmental fuel specifications are introduced by EU Directives. Of relevance to the current study is the EU diesel fuel specification *2009.01*, which sets a maximum sulfur limit of 10 ppm (“sulfur-free”) for diesel fuel for highway and non-road vehicles.

63 Outcomes from the EU regulatory review process include recommendations to extend regulations to include greater than 560 kW and 8 to 19 kW engines/equipment, but to continue to exclude 0-8 kW engines from regulation (Zeebroeck and Vanhove, 2009).

Review of Non-road Mobile Machinery Directive

A review of the 1997 EU Non-road Mobile Machinery (NRMM) Directive was conducted by the EU Directorate-General Joint Research Centre and Institute for Environment and Sustainability in 2007. The recommendations of this review and outcomes of the subsequent impact assessment (2009) are considered in some length as they hold significant relevance to this study.

The main conclusions and recommendations of the NRMM Directive review[(64)] are as follows:

- The main NRMM sources are the agriculture and construction sectors. Rail and inland waterway vessels contribute to emissions, but much less than the other two sectors.

- Problems arising from the application of Stage IIIB and Stage IV emission limits to special small tractors were highlighted. It was recommended that the special narrow track tractors used in vineyards and orchards be exempted from the emission Stage IIIB and Stage IV standards.

- It was recommended that more work be done in the fields of in-use conformity, off-cycle emissions and cycle bypass prevention.

- With respect to engine power classes below 19 kW and above 560 kW, several options were identified. The proposal favoured by industry was noted to be a partial alignment with the US regulations by setting US emission limits for engines in the power band 8-19 kW and by setting US emission limits for engines above 560 kW.

- The misalignment between US and Europe regarding reference fuel specification requires attention.

- The assessment of future inland waterway transport emission limits resulted in proposals for Stage III equivalent limits. It was stipulated that these limits should be applicable to all engines used on inland waterway vessels and a review of possible Stage IV emission limits should be finalised by the year 2012.

In assessing the significance of engines in the less than 19 kW power band, the contribution of 0-8 kW and 8-19 kW engines to total land based compression ignited engine emissions were considered. Engines less than 19 kW were noted to contribute only 1% of NO_x and 2% of PM of total emissions (despite comprising 23% of engine sales), of which the 0-8 kW engines contributed only 0.04% and 0.1% of total NO_x and PM emissions respectively. (The 0-8 kW engine NO_x and PM emissions therefore comprised only 3% of the entire 0-19 kW engine contribution.)

64 Krasenbrink A and Dobranskyte-Niskota AD (2007). 2007 Technical Review of the NRMM Directive 1997/68/EC as amended by Directives 2002/88/EC and 2004/26/EC, Draft Final Report, European Commission, Institute for Environment and Sustainability.

Large engines (greater than 560 kW) were noted to comprise only 1% of engine sales, but to contribute 9% of the total NOx and 7% of total PM across all land based compression ignited engines.

An impact assessment on the recommended options for revision of the 1997 NRMM Directive[65] considered the compliance costs, socio-economic impacts, environmental impacts and efficiency (costs versus benefits) of the recommended options. The findings of the impact assessment support the setting of US equivalent emission limits for 8-18 kW and greater than 560 kW engines, whilst excluding 0-8 kW engines from regulation.

Regulation of Construction Engines in Switzerland

A number of initiatives for the management of emissions from non-road engines have been implemented in individual European countries. Although a detailed review of such initiatives have not been undertaken, reference is made to regulatory developments in Switzerland. Switzerland is not part of EU, despite it having a bilateral agreement with EU and thus adopting some of the EU legislation.

In 2002 Switzerland extended the requirement for diesel particulate filters (previously required for underground equipment) to be implemented for general construction engines. The so-called BUWAL directive required that diesel engines of above 37 kW and operating within large construction sites be fitted with particulate filters by 2003, with engines of 18-37 kW implementing this measure by 2005. This requirements applies to new and in-service equipment. Particulate filters are not required for short duration equipment deployment of maximum one day per construction site per year. Performance criteria are specified for particulate filters and other PM emission control devices.

7.1.4 Japan

As in the United States, Japan has a three pronged approach to managing emissions from non-road diesel engines, namely: (i) emission standards, (ii) fuel specifications, and (iii) a recognition system for voluntary action.

Emission Standards and Fuel Quality Specifications

An overview of Japan's emission standards for Special/Non-road Motor Vehicles is given in **Section 4.**

There are two quality standards for diesel fuels in Japan: (i) a mandatory standard specified in the *Law on the Quality Control of Gasoline and Other Fuels* ("Quality Assurance Law" and a voluntary Japanese Industrial Standard (JIS) K 2204 *Diesel Fuel*.

The Quality Assurance Law provides mandatory requirements for sulfur, cetane index and T90 distillation temperature that diesel fuel must meet. This Law was amended in 2007 to include Japanese biodiesel standards. JIS K 2204 specifies five grades of diesel fuel, the main difference between each grade is the low temperature operability limits.

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65 Van Zeebroeck B, Vanhove F and Franckx L (2009). Impact Assessment Study – Reviewing Directive 97/68/EC – Emissions from non-road mobile machinery, Final Report, European Commission, 30 January 2009.

Diesel sulfur content has been managed downwards in Japan from 0.2% (1994), to 500 ppm (1997), to 50 ppm (2005), and to 10 ppm (2007). It should however be noted that 10 ppm sulfur diesel was introduced earlier (2005) throughout much of Japan through a voluntary effort of the Japanese petroleum industry.

Although most Japanese non-road equipment use No. 2 diesel fuel grade (which complies with the sulfur limits given above), some using fuel oil equivalent to No. 1 of Category I specified by JIS K 2205 the sulfur limit of which remains at 0.5%.

Portable/Transportable Equipment (Recognition System)

Under this recognition system which became effective in 2006, manufacturers may apply for their engines to be recognized as ‘low emission engines’ for use in designated ‘low emission construction machinery’. The recognition system applies to portable and transportable (i.e., non-self-propelled) equipment, which are not regulated under the Special/Non-road Motor Vehicle regulations (as given in **Table 16**). The voluntary emission limits are outlined in **Table 31**.

Table 31: Japan’s Recognition System Emission Limits for Portable/Transportable Equipment

Power (P)	CO	HC	NO_x	PM	Smoke
kW	g/kWh				%
8 ≤ P < 19	5.0	7.5(a)		0.4	40
19 ≤ P < 37	5.0	1.0	6.0	0.4	40
37 ≤ P < 56	5.0	0.7	4.0	0.3	35
56 ≤ P < 75	5.0	0.7	4.0	0.25	30
75 ≤ P < 130	5.0	0.4	3.6	0.2	25
130 ≤ P < 560	3.5	0.4	3.6	0.17	25

(a) NOx + HC

7.1.5 China

China has measures in place to regulate the sulfur content of diesel, and emissions from non-road diesel equipment.

Emission standards which have recently been adopted in China for non-road diesel were outlined in **Section 4**. It is notable that these standards were based on EU Stage I/II standards, but that the applicability of regulations was extended to include emission standards for small diesel engines.

Low sulfur diesel fuel (S ≤ 500 ppm) has been available nationwide in China since 2004. In the Beijing region, the maximum sulfur level in diesel fuels is 50 ppm (effective 2008).

7.2 Diesel Retrofit Schemes for In-Service Non-road Diesel Engines

Diesel retrofit programs have been widely implemented globally including in Australia. Although such programs have tended to focus on on-road diesel vehicles (as in the case of Australia), increasing emphasis is being placed on diesel retrofit programs for non-road diesel equipment. This is particularly notable in the US.

To meet the objectives of the current study a brief overview is provided of the NSW Diesel Retrofit Program to demonstrate the manner in which such programs are being implemented locally for on-road vehicles. A more detailed synopsis is provided of the US Voluntary Retrofit Program for non-road diesel engines, with reference made to the costs of in-service non-road diesel retrofits compared to onroad diesel retrofits and regulation of new non-road diesel engines.

7.2.1 Australia and NSW

The Diesel National Environment Protection Measure (Diesel NEPM), introduced by the National Environment Protection Council (NEPC) in June 2001, provides guidelines for a range of programs to reduce pollution from in-service diesel vehicles. It complements new vehicle emission and fuel quality standards, and includes guidelines for smoky vehicle programs, emissions test and repair programs, an audited maintenance program for diesel vehicles and diesel vehicle retrofit programs.

Although the Diesel NEPM, and the NSW Diesel Retrofit Program being implemented under the Diesel NEPM, are applicable to **on-road** vehicles, it is of interest to see how such programs are being implemented locally.

The NSW Diesel Retrofit Program aims to reduce emissions of heavy diesel vehicles operating in the Sydney Greater Metropolitan Region by fitting emissions-reducing devices to the exhaust systems of existing trucks. Funding support from the Commonwealth and DECCW have been provided to the Roads and Traffic Authority (RTA) for its retrofitting of diesel trucks with three types of emission control devices, viz. Diesel Oxidation Catalysts, Diesel Particulate Filters or Partial Particle Filters. As at July 2008, 71 fleets had participated in the program and 365 vehicles had been fitted with these devices.

The NSW Diesel Retrofit Program represents a co-contribution style retrofit program, with both the NSW government and the vehicle operator contributing to the cost of the device fitted.

7.2.2 United States

The US approach to managing emissions from in-service non-road diesel equipment is due to the outcome of a federal court case. In the case Engine Manufacturers Association vs US-EPA (1996), it was ruled in the D.C Circuit Federal Court of Appeals that the US-EPA does not have adequate general statutory authority to implement emission standards (such as federally mandated retrofit programs) from existing non-road diesel engines. The US-EPA currently focuses on voluntary retrofit programs for in-service diesel engines.

As part of the US-EPA's National Clean Diesel Campaign (NCDC), the US-EPA addresses diesel engines already in use by promoting a variety of emission reduction strategies such as retrofitting, repairing, replacing and repowering engines, reducing idling and switching to cleaner fuels. These programs are being accomplished in partnership with state and local governments, environmental groups and industry.

The *Diesel Emissions Reduction Act* (DERA) 2005 establishes a voluntary national and state-level grant and loan program to reduce emissions from existing diesel engines through clean diesel retrofits. The US-EPA estimates that, if DERA is fully funded, it would reduce particulate matter emissions by 70,000 tons.

The US-EPA's Voluntary Diesel Retrofit Program aims to encourage implementation of voluntary diesel retrofits at the community level. *Clean Air Count*s provides grants to area municipalities to develop non-road diesel retrofit programs. Several options are available to fleet owners and operators who are considering improving the emission performance of their diesel engines. These options include retiring older engines; converting engines to run on cleaner, alternative fuels like compressed natural gas; and retrofitting older engines with modern emission control. In considering options, fleet owners and operators are advised to evaluate the cost and benefits of each option. Extensive recommendations are outlined by the US-EPA to assist fleet owners in their design of successful diesel retrofit projects.

The US-EPA evaluated the cost effectiveness of retrofitting non-road equipment with diesel oxidation catalysts (DOCs) and catalysed diesel particulate filters (CDPFs) which are two of the most common PM emission reduction technologies for diesel engines. In addition to this selective catalytic reduction (SCR) systems and engine upgrade kits for NO_x reduction were evaluated. The heavy-duty non-road diesel engine retrofit costs were compared to other initiatives, including the Non-road Tier 4 emission regulations, as follows[(66)]:

Heavy-Duty Non-road Diesel Engine Retrofits Costs (US$)	Other Initiatives (costs in US$):	
$18,700 – $87,600/ton PM reduction	Retrofitting School Buses and Class 6-8c Trucks	$11,000 – $69,900/ton PM
	Urban Bus Retrofit and Rebuild program	$31,500/ton PM
	2007 Heavy-Duty Highway diesel emission standards (on road)	$14,200/ton PM
	Non-road Tier 4 emission standards	$11,200/ton PM
$1,900 - $19,000/ton NO_x	2007 Heavy-Duty Highway diesel emission standards (on road)	$2,100/ton NO_x
	Non-road Tier 4 emission standards	$1,000/ton NO_x

US-EPA concluded that heavy-duty non-road diesel engine retrofits can be cost effective in reducing air pollution and health impacts associated with diesel emissions. It is however notable that the costs of retrofitting non-road diesel engines are significantly higher than those established for the Non-road Tier 4 emission standards (by factors of between 1.7 and 7.8 for PM reductions and between 1.9 and 19 for NO_x reductions).

66 US-EPA (2007). Diesel Retrofit Technology, An Analysis of the Cost-Effectiveness of Reducing Particulate Matter and Nitrogen Oxides Emissions from Heavy-Duty Non-road Diesel Engines Through Retrofits, Office of Transportation and Air Quality, Report No. EPA420-R-07-005, May 2007,

7.2.3 California

In July 2007 the California Air Resources Board (ARB) approved a regulation to reduce emissions from existing off-road diesel vehicles used in California in construction mining and other industries. This regulation requires fleets to apply exhaust retrofits that capture pollutants before they are emitted to the air, and to accelerate turnover of fleets to newer, cleaner engines.

The regulation takes effect earliest (2010) for the largest fleets (those with greater than 5,000 hp of affected vehicles, excluding vehicles operating less than 100 hours per year). The compliance dates for medium fleets (2,501 to 5,000 hp) are in 2013, with requirements delayed until 2015 for fleets of 2,500 hp or less.

Health benefits due to the implementation of the CARB regulation ($18 to $26 billion) are estimated to exceed the total cumulative cost of the regulation ($3 to 3.4 billion)[(67)].

7.3 Summary of Measures and Targetted Products

Emission management measures implemented internationally for new and in-service non-road diesel engines/equipment are summarised in subsequent subsections, and reference made to the products which are most typically targeted by non-road diesel regulations. The applicability of such targeted products and emission reduction measures for Australia is evaluated in **Section 9**, following the estimation of emission reductions achievable through the control of emissions for various product sub-populations (**Section 8**).

7.3.1 Emission Management Measures for New Non-road Diesel

Several types of measures have been identified from the review of international emission management measures for **new** non-road diesel engines and equipment:

- Explicit government regulation of non-road diesel engines and equipment, including the stipulation of emission limits for various engine categories and power bands and compliance testing procedures.
- Co-regulation, with best (good) practice standards being voluntary, but industry (manufacturers and importers) adopting them by agreement.
- Voluntary emission standards and recognition programs.
- Fuel quality standards, specifically sulfur content requirements.
- Emission limit requirements for new non-road diesel equipment stipulated as part of government contracts.

67 CARB (2007). Technical Support Document: Proposed Regulation for In-use Off-road Diesel Vehilces, California Air Resources Board, April 2007.

Other potential options for the management of emissions from new non-road diesel engines include:

- No action (i.e. business as usual). Neither government nor industry takes action to reduce emissions by any means.
- Quasi-regulation (as an alternative to co-regulation), where good practice standards are advisory and adopted by industry, but the government does not register or certify the industry agreement and therefore has no statutory force for standards. No enforcement is undertaken.
- Self regulation. Industry acceptable standards are adopted but are advisory only. Industry (manufacturers and importers) indicates general support for such standards only and no enforcement is undertaken.
- Alternative instruments, such as the publication of industry acceptable benchmarks, financial incentives/disincentives, and education and awareness programs for suppliers and/or users.

Emission reduction measures targeting non-road diesel engines/equipment may broadly be categorized into two main types:

- Product-based Emission Reduction Measures,
- Fuel Quality Management Measures.

Internationally the trend has been towards the use of product-based and fuel quality related measures in combination to more efficiently and cost-effectively reduce emissions from the non-road diesel sector. The incorporation of sulfur-sensitive control technologies such as catalytic particulate filters and NOx adsorbers in engines to meet higher order (Tier 4, Stage IIIb) standards has also necessitated reductions of sulfur content in non-road diesel fuels. In the assessment of product-based emission reduction measures it will be assumed that such measures are complimented by appropriate fuel quality requirements.

7.3.2 New Products Typically Targetted for Reduction

Market Segments

Market segments and applications targeted by non-road diesel engine/equipment emission management measures abroad most typically include the following diesel-powered engines/equipment:

- Agricultural equipment and vehicles (including tractors and other self-propelled machinery, pumps and generators).
- Construction and mining equipment and non-road vehicles.

- General industrial equipment and non-road vehicles, including aviation service equipment.
- Lawn and garden equipment.
- Light commercial equipment, including pumps and compressors.
- Power generation sets, including gen sets over 900 kW (in the case of the US).
- Logging equipment.
- Marine engines – specifically small 37 kW engines in the case of the US, and inland water vessels in the case of the EC.
- Rail traction engines (EU only; US makes provision for locomotives under separate regulations).

Engine Rating Categories

Although distinctions are made between market segments in emissions inventories, regulations and regulatory impact assessments for non-road diesel engines in the US, Europe and elsewhere tend to focus on *engine rating classes*. The main reasons for this include: efficiency of regulation, and the fact that the same diesel engines are used in equipment and vehicles implemented within several market segments.

The engine power rating ranges which are covered by non-road diesel regulations include non-road diesel engines (across the above mentioned market segments) within the following power bands:

<8 kW	US; Canada; China; India
8 – 19 kW	US; Canada; China; India (being considered by EU)
19 – 560 kW (various bands)	US; Canada; China; India; EU; Japan
>560 kW	US; Canada; (being considered by EU)

Niche Markets Sub-sectors

International experience shows setting emission limit requirements for new non-road diesel equipment under government contracts was effective for heavy industrial (construction, mining) equipment, specifically in the power range over 37 kW.

7.3.3 In-Service Products Typically Targetted for Reduction

Diesel retrofit programs targetting heavy industrial (construction, mining) equipment represents the most typical emission reduction measure implementable for in-service non-road diesel equipment. Such programs may be either voluntary (with or without incentives) or mandatory.

8 Emission Reductions and Health Benefits of Compliance with International Standards

Understanding the environmental benefits of managing emissions from specific product sub-populations (market segments /applications / engine power bands) requires an assessment of the current emissions of such product types and the emission reduction potential given compliance with international standards.

Section 8.1 describes the study assumptions and the emission estimation methodology applied in the current study for the estimation of base case non-road diesel engine emissions and potential emission reductions.

Section 8.2 documents estimated emissions from new engines/equipment when in operation during the 2008 to 2030 period, taking into account engine/equipment population numbers and emission performances of engines/equipment sold in Australia in 2008.

Section 8.3 presents emission reduction potentials calculated, assuming compliance with US non-road diesel emission limits. Emission reductions were calculated taking into account the existing emission performance of new engines/equipment being imported into Australia as documented in **Section 5.5**.

Section 8.4 outlines specific non-road diesel sub-populations which may be prioritised on the basis of emission reductions and achievable health benefits.

The benefits of avoided emissions, specifically health-related benefits, are considered in **Section 8.5**.

8.1 Emission Estimation Methodology for New Engines/Equipment

To assess the potential benefits of non-road diesel emission management, emissions were estimated for new (and imported used) non-road diesel engines/equipment sold into the Australian market during the 2009 to 2030 period, excluding emissions due to in-service equipment in place by 2008. (Emission projections for in-service non-road diesel equipment are presented in **Section 3**.)

Emissions for new (and imported used) non-road diesel engines/equipment sold into the Australian market and after 2008 were projected for selected years during the 2009 to 2030 period, namely 2009, 2020 and 2030. Given the growth in the population of post-2008 engines/equipment, and the scrappage of the current in-service engines/equipment population, post-2008 units are projected to comprise the bulk of the total population by 2030. Whereas emission projections for 2009 and 2020 are indicative of a portion of the total non-road diesel related emissions, emission estimates for 2030 are expected to be more representative of the total non-road diesel population.

Emission projections were undertaken for base case (business as usual) and controlled emission scenarios. Differences between base case and controlled case emissions reflect the emission reductions achievable through the implementation of controls.

Major Assumptions and Limitations

The following major study assumptions and limitations should be noted:

- Engine/equipment population projections for the 2009 to 2030 period were based on the assumption of a zero growth rate in new engine/equipment numbers with 2008 new engine/equipment numbers assumed for all years during this period(68). The growth in equipment population during the 2009 to 2030 period was therefore primarily a function of new equipment sales and equipment retirement. Equipment retirement was estimated based on specific scrappage rates determined by engine/equipment sub-population (type/application/power rating).

- Uncertainties regarding future changes in the emission performance of non-road diesel engines/equipment, given 'business as usual', represent a significant barrier to projecting base case emissions from the sector with confidence. For this reason, upper and lower bound base case scenarios were defined based on different assumptions regarding future trends in emission performance:

  - **Upper bound (conservative) base case scenario** – assuming the emission performance status of engines/equipment inventoried for 2008 would remain representative of the emission performance status of the engines/equipment sold into Australia during the 2009 to 2030 period.

    This scenario is defined as being relatively conservative given that the emission performance may improve, at least within some market segments, due to market forces and voluntary measures. On the other hand, in the absence of local regulations and given increasing regulation abroad, there may be a growth in the inflow of new and used equipment with poorer emission performances. This could potentially result in an increase in the percentages of non-compliant and Tier 1 and Tier 2 compliant equipment over time. The implications of this eventuality could not be quantitatively evaluated in the current study.

  - **Lower bound (best case) base case scenario**(69). This scenario is based on the premise that there may be a gradual improvement in the overall emission performance of non-road diesel engines/equipment over time. It was specifically assumed that all engines/equipment would be at least Tier 2 compliant by 2020 with 50% of the Tier 2 compliant engines (as at 2008) becoming Tier 3 compliant. Tier 3 compliant engines (as at 2008) were assumed to remain Tier 3 compliant. The fraction of Tier 4 interim compliant engines (as at 2008) was assumed to remain Tier 4 interim compliant engines. No uptake of Tier 4 final compliant engines was assumed due to potential cost and fuel quality constraints.

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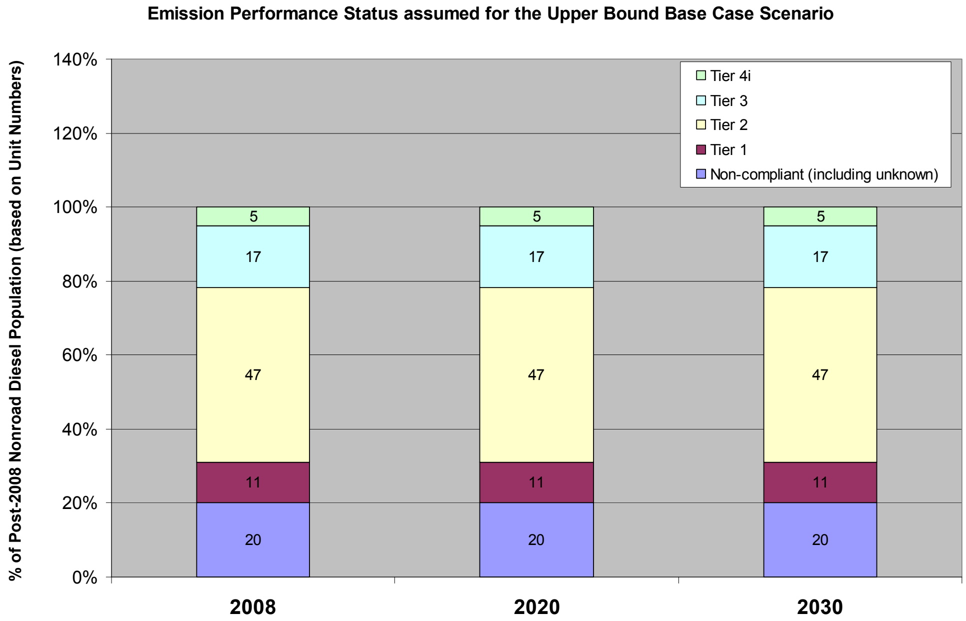
68 According to ABARE (2006), the growth rate in petroleum products, including ADO, is projected to be 1.4% per annum during the 2005 to 2030 period. Projections are not however published for individual fuel types. It is also indicated by ABARE that such projections include a significant increase in petroleum consumption by road and air transportation sectors. In the absence of projections specific to the non-road diesel sector, it was decided to assume a zero growth rate so as not to risk exaggerating base case emissions from this sector.
69 This base case scenario could also be indicative of a 'gradual emission control' case in which Tier 2 equivalent emission standards are introduced in the short to medium term, with Tier 3 equivalent emission standards being subsequently implemented (for engines over 19 kW).

The projected changes in the emission performance status of non-road diesel engines/equipment sold into the Australian market post 2008 is illustrated for the upper and lower bound base case scenarios in **Figure 19**.



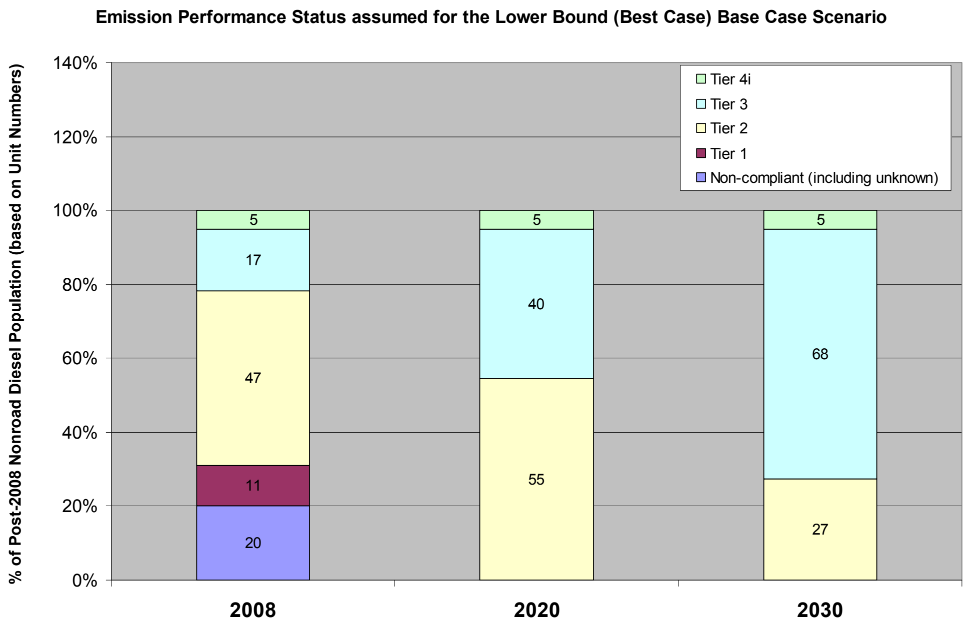


Figure 19: Emission performance status of the non-road diesel population assumed for the Upper Bound and Lower Bound (Best Case) Base Case Scenarios for engines/equipment sold in and after 2008.

- Engines/equipment with an unknown compliance status (projected to comprise 13% of non-road diesel engines/equipment in 2020 and 15% in 2030) were treated as being non-compliant for upper bound base case emission estimation purposes.

- For the purpose of estimating emissions, no distinction was made between certified and compliant (but uncertified) engines. Emissions estimated for certified engines would however carry a greater degree of confidence.

- Non-road diesel regulations abroad typically exclude equipment used underground, with emissions from such equipment being regulated by other regulations. In the current study it was not possible to distinguish between equipment applied above and below ground.

- Non-road diesel engines/equipment are assumed to be fuelled by diesel which meets the Australian automotive diesel oil sulfur requirement of 10 ppm. It is however noted that off-specification diesel with higher sulfur contents may be used for non-road diesel applications. The use of such fuels will result in higher PM emissions than are estimated and presented for the base case within the current section.

- A control scenario was defined to assess maximum emission reductions achievable through the implementation of emission standards equivalent to those implemented in the US.

  Early compliance was assumed to facilitate the quantification of emissions reduction achievable. It was assumed that engines/equipment would be Tier 4 interim compliant prior to 2015 and Tier 4 final compliant post 2015 (in line with the US non-road diesel regulation compliance timeframes). Possible additional, more stringent emission standards developed post US Tier 4 final could not be accounted for.

Quantification of Emission Sources

Particulate matter (PM), oxides of nitrogen (NO_x) and volatile organic compounds (VOC) emissions were estimated. The first four species are exhaust emissions, emitted directly as a result of diesel fuel combustion in the engine. VOC emissions include both exhaust and evaporative components. The exhaust component comprises hydrocarbons (HCs) emitted as products of combustion, with the evaporative component including compounds released from unburned fuel during engine operation (termed ‘crankcase emissions’).

US-EPA NON-ROAD 2008 emission factors used in the quantification of non-road diesel engine exhaust and evaporative emissions are given in **Appendix H**. Emission inputs used in the exhaust calculations for engine/equipment sub-populations are given in **Appendix I.**

Detailed VOC speciation profiles are lacking for most non-road diesel engine/equipment sub-populations. The current study made reference to the major air toxics for which provision is made in the US-EPA land-based non-road diesel VOC emission estimate, namely benzene, formaldehyde, acetaldehyde, 1.3-butadiene and acrolein. The fractions used for each air toxics pollutant is given in **Appendix H**.

$PM_{2.5}$ emissions were estimated as a component of PM_{10} emissions, the less than 2.5 micrometer fraction being estimated to compose 97% of PM_{10} emissions[70].

8.2 Base Case Emissions for Post-2008 Non-road Diesel Products

Emission estimates by market segment, application (equipment type) and engine rating are given in **Appendix J**. Key results are presented and discussed in this subsection.

8.2.1 Overall Base Case (Business as Usual) Emissions

Base case (business as usual) emissions estimated for years 2009, 2020 and 2030 are presented in **Table 32** for upper bound and **Table 33** for lower bound estimates.

Taking into account the sale of new and imported used engines/equipment and the scrappage of units during the 2009 to 2020 period, the total non-road diesel population (in terms of post-2008 engines/equipment) is estimated to be about 454,000 by 2020. By 2030 the population is estimated to have grown to about 616,000. This latter figure approaches the estimated in-service engine/equipment population which is expected to be in the range of ~550,000 (based on 2003 estimates by PAE 2005 [71] to 620,000 (projected for 2008).

Given the growth in the population of post-2008 engines, and the scrappage of the in-service engines/equipment population, post-2008 units are projected to comprise the bulk of the total population by 2030. Whereas emission projections for 2009 and 2020 are indicative of a portion of the total non-road diesel related emissions, emission estimates for 2030 are expected to be more representative of the total non-road diesel population.

Annual PM_{10} emissions due to non-road diesel engines/equipment were projected to be in the range of 7.8 ktpa (best case) to 14.6 ktpa by 2030 given base case (business as usual) operations, with 97% of such emissions being $PM_{2.5}$ (**Table 32, Table 33**). Annual NO_x emissions are estimated to be of the order of 82.6 ktpa to 117.4 ktpa by 2030.

The base case non-road diesel emission estimates presented in **Table 32** and **Table 33** excludes the used vehicle propulsion engines being imported into the country, of which there were about 1,200 in 2008. Despite being characterised as engines for both on-road and off-road vehicles it is feasible that such engines could be applied primarily for non-road diesel applications. Assuming such engines are applied within non-road applications and are non-compliant with international emission standards, it is estimated that their use could account for an additional 100 tpa of PM_{10} emissions by 2030.

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70 US-EPA (2004). Exhaust and Crankcase Emission Factors for Non-road Engine Modelling – Compression Ignition, EPA420-P-04-009, April 2004.
71 PAE (2005). Management Options for Non-road Engine Emissions in Urban Areas, Report compiled by Pacific Air and Environment on behalf of the Department of the Environment and Heritage, November 2005.

Table 32: Upper Bound Base Case emissions from non-road diesel engines/equipment

Species	Annual Emissions (tonnes/annum)		
	2009	2020	2030
PM_{10}	1,300	11,211	14,596
$PM_{2.5}$	1,261	10,874	14,159
Total VOCs	1,190	9,105	11,586
NOx	12,987	95,051	117,415
Benzene	24	182	232
Formaldehyde	140	1,074	1,367
Acetaldehyde	63	483	614
1,3-Butadiene	2	18	23
Acrolein	4	27	35
Engine/Equipment Population (number of post-2008 units)	56,233	454,281	615,833

Note that the table represents emissions estimated for new (and imported used) non-road diesel engines/equipment sold into the Australian market during the 2009 to 2030 period, excluding emissions due to in-service equipment in place by 2008.

Table 33: Lower Bound Base Case emissions from non-road diesel engines/equipment

Species	Annual Emissions (tonnes/annum)		
	2009	2020	2030
PM_{10}	1,300	6,602	7,808
$PM_{2.5}$	1,261	6,404	7,573
Total VOCs	1,190	5,504	6,145
NOx	12,987	73,582	82,556
Benzene	24	110	123
Formaldehyde	140	649	725
Acetaldehyde	63	292	326
1,3-Butadiene	2	11	12
Acrolein	4	17	18
Engine/Equipment Population (number of post-2008 units)	56,233	454,281	615,833

Note that the table represents emissions estimated for new (and imported used) non-road diesel engines/equipment sold into the Australian market during the 2009 to 2030 period, excluding emissions due to in-service equipment in place by 2008.

8.2.2 Base Case Emissions by Market Segment and Equipment Type

Upper Bound Base Case emissions by market segment are presented in **Table 34, Table 35** and **Table 36** respectively for 2009, 2020 and 2030 respectively. Contributions of market segments to 2020 and 2030 particulate emissions are illustrated in **Figure 20**.

Table 34: Upper Bound Base Case emissions from non-road diesel for 2009

Market Segment	Upper Bound Base Case Emissions (tpa) for 2009			
	PM_{10}	$PM_{2.5}$	Total VOCs	NO_x
Agricultural	189.1	183.4	174.0	1,657.8
Forestry	2.1	2.1	1.5	19.6
General Industrial	138.6	134.5	166.6	1,831.8
Heavy Industrial (Construction, Mining)	804.3	780.1	635.6	7,547.5
Lawn and Garden	2.3	2.3	3.3	30.3
Light Commercial	3.2	3.1	3.1	29.3
Marine	0.6	0.6	1.6	9.4
Power Generation Drive	17.9	17.4	27.4	330.8
Power Generation Sets	141.3	137.1	177.1	1,530.2
Total	1,299.6	1,260.6	1,190.3	12,986.8
Market Segment	% Contribution to Base Case Emissions for 2009			
	PM_{10}	$PM_{2.5}$	Total VOCs	NO_x
Agricultural	14.6	14.6	14.6	12.8
Forestry	0.2	0.2	0.1	0.2
General Industrial	10.7	10.7	14.0	14.1
Heavy Industrial (Construction, Mining)	61.9	61.9	53.4	58.1
Lawn and Garden	0.2	0.2	0.3	0.2
Light Commercial	0.2	0.2	0.3	0.2
Marine	0.0	0.0	0.1	0.1
Power Generation Drive	1.4	1.4	2.3	2.5
Power Generation Sets	10.9	10.9	14.9	11.8
Total	100.0	100.0	100.0	100.0

Note that the table represents emissions estimated for new (and imported used) non-road diesel engines/equipment sold into the Australian market during 2009, excluding emissions due to in- service equipment in place by 2008. (Post-2008 non-road diesel population is estimated to be 56,245 units.)

Table 35: Upper Bound Base Case emissions from non-road diesel for 2020				
Market Segment	Upper Bound Base Case Emissions (tpa) for 2020			
	PM_{10}	$PM_{2.5}$	Total VOCs	NO_x
Agricultural	2,184.0	2,118.4	1,854.9	16,657.9
Forestry	16.4	15.9	9.9	122.2
General Industrial	1,332.2	1,292.2	1,480.6	15,097.4
Heavy Industrial (Construction, Mining)	6,626.3	6,427.5	4,548.5	53,095.1
Lawn and Garden	24.8	24.1	31.2	266.8
Light Commercial	35.3	34.2	31.8	274.2
Marine	2.6	2.5	6.0	38.3
Power Generation Drive	86.9	84.3	126.9	1,282.6
Power Generation Sets	902.4	875.3	1,015.6	8,216.9
Total	11,210.8	10,874.5	9,105.5	95,051.3
Market Segment	% Contribution to Base Case Emissions for 2020			
	PM_{10}	$PM_{2.5}$	Total VOCs	NO_x
Agricultural	19.5	19.5	20.4	17.5
Forestry	0.1	0.1	0.1	0.1
General Industrial	11.9	11.9	16.3	15.9
Heavy Industrial (Construction, Mining)	59.1	59.1	50.0	55.9
Lawn and Garden	0.2	0.2	0.3	0.3
Light Commercial	0.3	0.3	0.3	0.3
Marine	0.0	0.0	0.1	0.0
Power Generation Drive	0.8	0.8	1.4	1.3
Power Generation Sets	8.0	8.0	11.2	8.6
Total	100.0	100.0	100.0	100.0

Note that the table represents emissions estimated for new (and imported used) non-road diesel engines/equipment sold into the Australian market during the 2009 to 2020 period, excluding emissions due to in-service equipment in place by 2008 (post-2008 non-road diesel population is estimated to be 454,281)

Table 36: Upper Bound Base Case emissions from non-road diesel for 2030				
Market Segment	Upper Bound Base Case Emissions (tpa) for 2030			
	PM_{10}	$PM_{2.5}$	Total VOCs	NO_x
Agricultural	3,552.3	3,445.7	2,815.57	25,095.6
Forestry	16.4	15.9	9.89	122.2
General Industrial	1,868.1	1,812.1	2,022.05	20,162.0
Heavy Industrial (Construction, Mining)	8,002.9	7,762.8	5,400.78	60,714.6
Lawn and Garden	31.5	30.6	38.25	326.0
Light Commercial	55.7	54.0	47.24	392.3
Marine	4.1	3.9	8.84	58.1
Power Generation Drive	106.5	103.3	152.98	1,458.0
Power Generation Sets	959.1	930.3	1,090.23	9,086.3
Total	14,596.5	14,158.6	11,585.8	117,415.1
Market Segment	% Contribution to Base Case Emissions for 2030			
	PM_{10}	$PM_{2.5}$	Total VOCs	NO_x
Agricultural	24.3	24.3	24.3	21.4
Forestry	0.1	0.1	0.1	0.1
General Industrial	12.8	12.8	17.5	17.2
Heavy Industrial (Construction, Mining)	54.8	54.8	46.6	51.7
Lawn and Garden	0.2	0.2	0.3	0.3
Light Commercial	0.4	0.4	0.4	0.3
Marine	0.0	0.0	0.1	0.0
Power Generation Drive	0.7	0.7	1.3	1.2
Power Generation Sets	6.6	6.6	9.4	7.7
Total	100.0	100.0	100.0	100.0

Note that the table represents emissions estimated for new (and imported used) non-road diesel engines/equipment sold into the Australian market during the 2009 to 2030 period, excluding emissions due to in-service equipment in place by 2008 (post-2008 non-road diesel population is estimated to be 615,833).

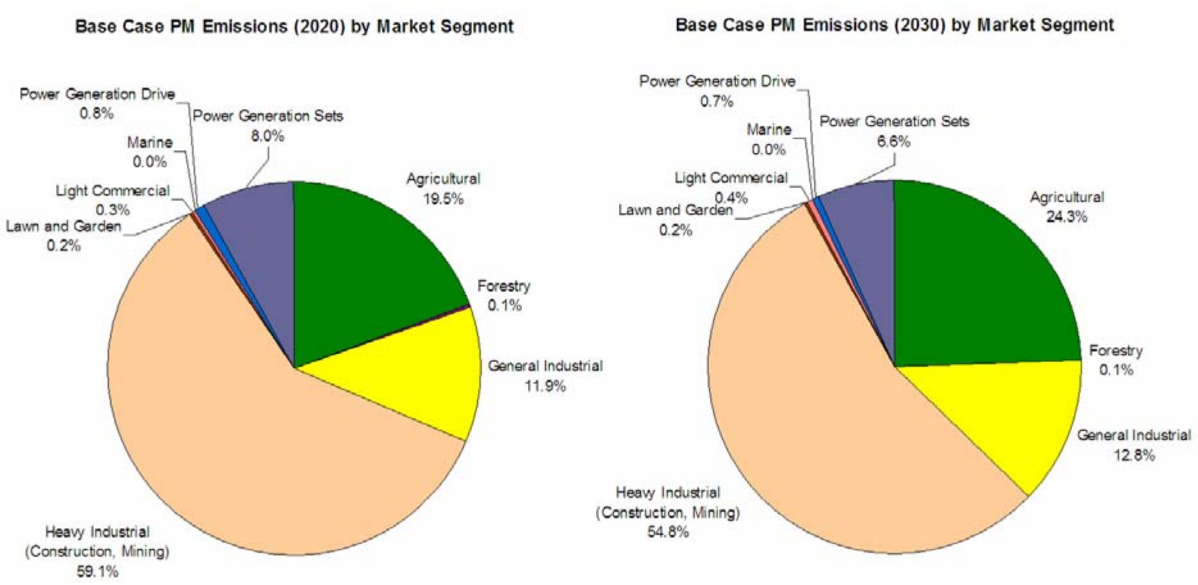

Figure 20: Upper Bound Base Case PM_{10} emissions by market segment for 2020 and 2030

Based on projected 2020 based case emissions the following is noted:

- Heavy industrial (construction, mining) contributes most significantly to total non-road diesel emissions, representing almost 60% of PM, 50% of total VOC and 55% of NO_x emissions.
- General industrial applications account for 12% of PM, 16% of total VOCs and NO_x.
- Agriculture accounts for about 20% of PM, NO_x and total VOC emissions.
- Power generation contributes over 8% of PM and $NO_x$and 12% of total VOCs.

The most significant change in market segment contribution to total emissions by 2030 is the increase in the contribution of agricultural applications. This is primarily a function of the longer lifespans of agricultural engines and equipment which results in a steeper growth in agricultural engine/equipment populations (**Figure 21, Table 37**). Whereas the agricultural equipment population is estimated to increase by 50% between 2020 and 3030, the heavy industrial (construction, mining) equipment population increases by 27%.

Despite its reduced contribution, heavy industrial (construction, mining) equipment continues to account for ~50% of PM, total VOCs and NO_x in 2030. By 2030 agriculture is estimated to account for 24% of PM.

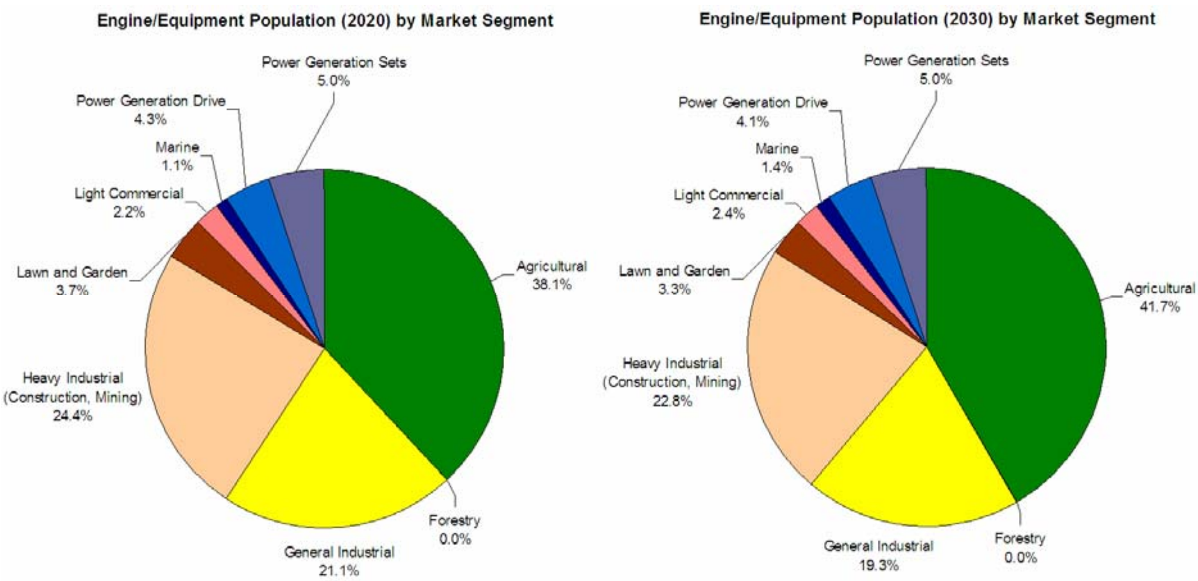

Figure 21: Projected non-road diesel engine/equipment population by market segment for 2020 and 2030

Table 37: Projected engine/equipment population by market segment for 2020 and 2030

Market Segment	Engine/Equipment Population (number of units)	
	2020	2030
Agricultural(a)	169,811	253,127
Forestry	185	185
General Industrial	93,852	116,811
Heavy Industrial (Construction, Mining)	108,703	138,088
Lawn and Garden	16,645	20,317
Light Commercial	9,790	14,595
Marine	4,963	8,437
Power Generation Drive	19,102	24,694
Power Generation Sets	22,291	30,262
Vehicle Propulsion	8,939	9,317
Total	454,281	615,833

(a) A significant component of agricultural equipment sales are small engines less than 19kW.

Particulate emissions by equipment type are illustrated for the heavy industrial (construction, mining) and general industrial segments in **Figure 22** and **Figure 23** respectively.

The most significant heavy industry equipment, excluding miscellaneous equipment and loose engines, were identified to be dump (off-highway) trucks and excavators.

Within the general industrial segment, miscellaneous loose diesel engines and pumps represent the most significant contributors.

Agricultural tractors were estimated to account for over 80% of all agricultural sector PM emissions.

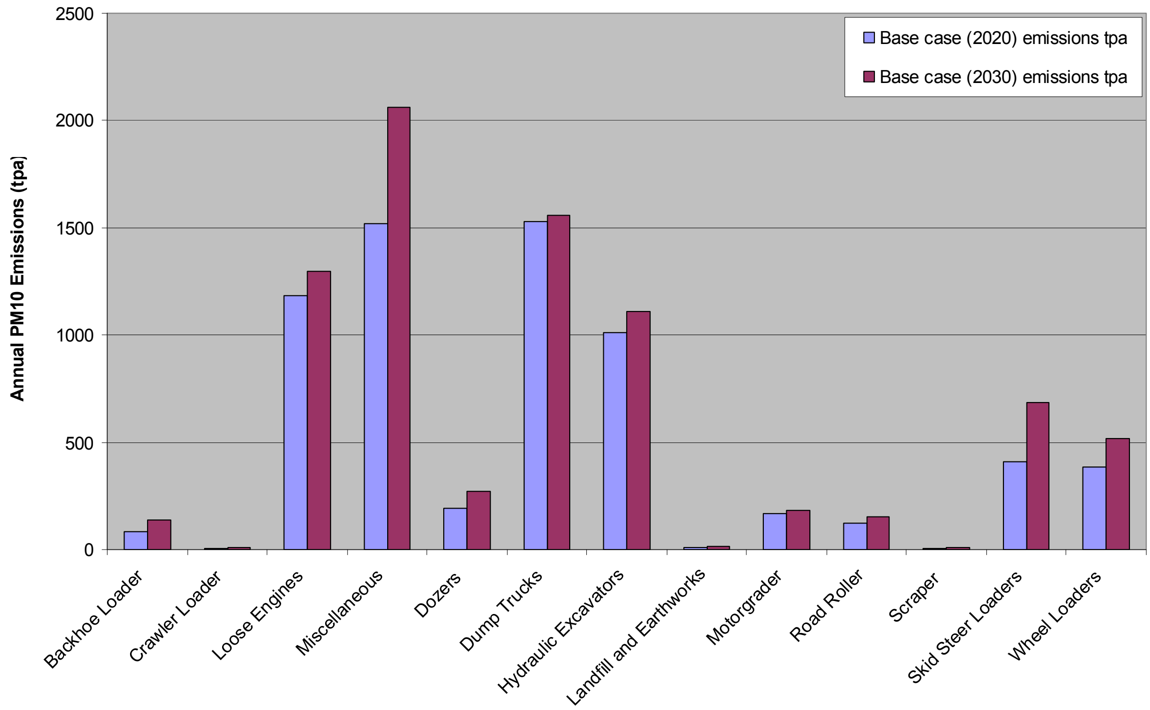

Figure 22: Upper Bound Base case heavy industrial (construction, mining) PM_{10} emissions by equipment type for 2020 and 2030

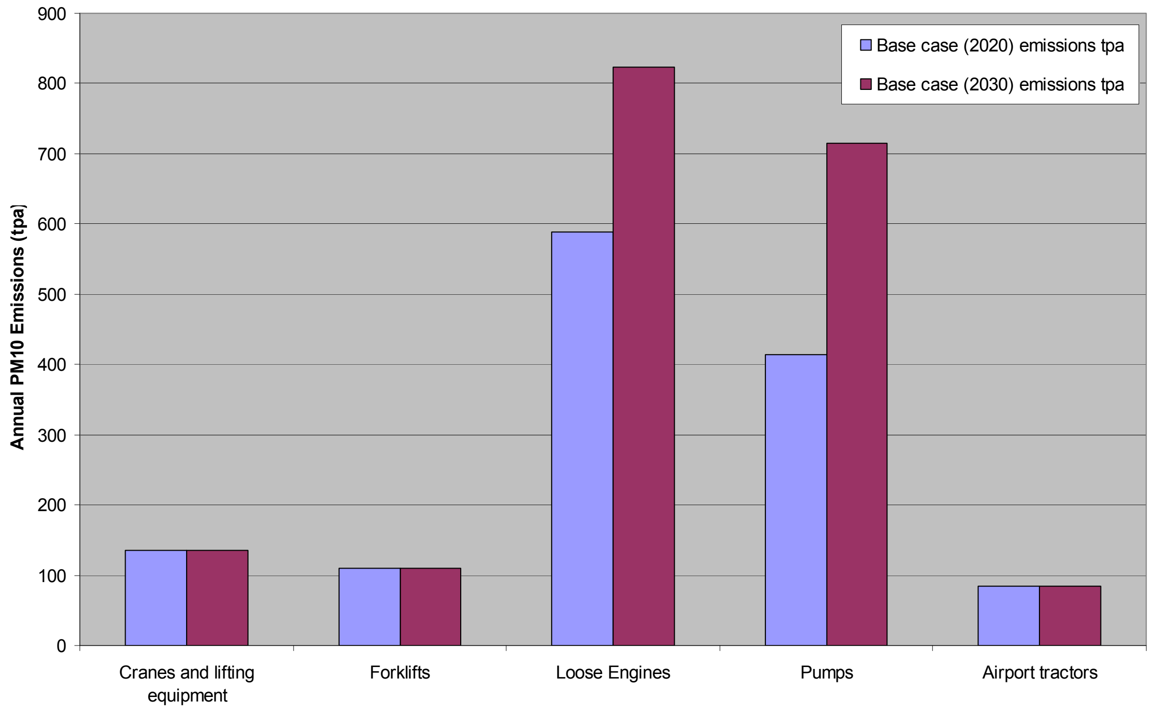

Figure 23: Base case general industrial PM_{10} emissions by equipment type for 2020 and 2030

8.2.3 Base Case PM Emissions by Engine Rating

The numbers of engines/equipment by power rating class projected for 2030 are given in **Table 38**. Upper Bound Base case PM_{10} emissions for 2030 are given by power rating class in **Table 39** to illustrate which classes of engine/equipment contribute most significantly to total emissions.

Table 38: Projected number of engines/equipment by power rating class for 2030

Power Rating Class (kW)	Projected No. of Engines/Equipment by Power Rating Class	Projected Percentage Engines/Equipment by Power Rating Class
<8	22,584	4
8 – 19	123,942	20
19 – 37	80,499	13
37 – 56	54,101	9
56 – 130	282,336	46
130 – 560	43,907	7
>560	8,464	1
Total	615,833	

Table 39: Upper Bound Base case non-road diesel PM_{10} emissions by power rating class (2030)

Power Rating Class (kW)	Base Case PM_{10} Emissions (tpa)	Base Case PM_{10} Emissions (%)
<8	20	0.1
8 – 19	308	2.1
19 – 37	595	4.1
37 – 56	786	5.4
56 – 130	7,385	51.7
130 – 560	3,075	21.0
>560	2,428	15.5
Total	14,597	

Engines in the 56 to 130 kW range are estimated to be responsible for about half the total PM emissions in 2030, with engines in the 130 to 560 kW range accounting for a further 20% and larger (greater than 560 kW) engines for 15% of emissions. When combined, engines/equipment with ratings greater than 56 kW account for 88% of total PM emissions (despite only accounting for 54% of the total number of engines).

Small engines (less than 19 kW) are estimated to contribute only about 2% of total PM emissions, despite accounting for almost a quarter of the total number of engines. The smallest engines (less than 8 kW) were estimated to contribute less that 0.1% of total PM emissions.

Upper Bound Base case PM_{10} emissions for 2030 are illustrated by power rating and market segment in **Figure 24**. The largest 56 to 130 kW power rating class is dominated by heavy industrial (construction, mining), agricultural and general industrial applications. Heavy industrial (construction, mining) engines/equipment and power generation sets are the most prominent market segments for the greater than 560 kW class.

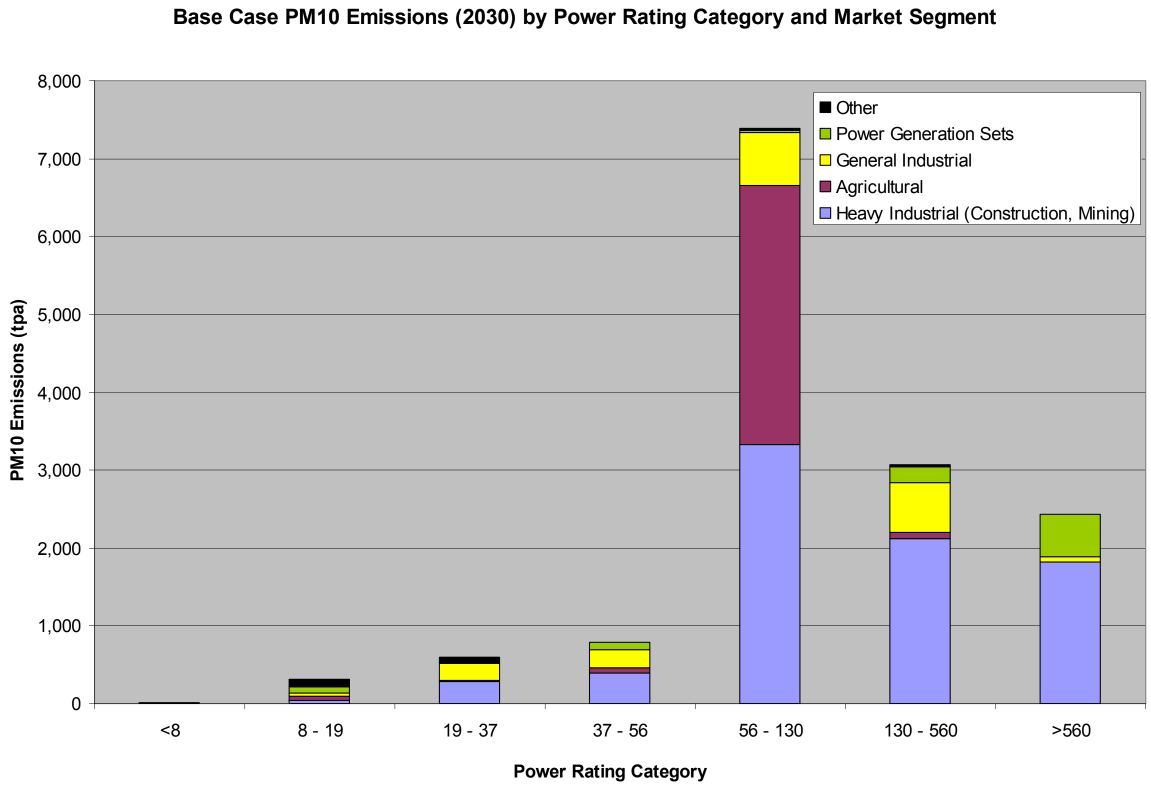

Figure 24: Upper Bound Base case PM_{10} emissions from non-road diesel engines for 2030 by power rating and market segment

8.2.4 Urban Share of Base Case Emissions

Air pollutants released within urban areas have greater impact potentials due to a combination of increased exposure potentials and the likelihood of cumulative air pollution concentrations due to the colocation of sources.

Given that the specific locations of engine/equipment applications are not known it is not possible to accurately quantify the extent of urban emissions. Generally, agricultural and forestry applications tend to be more remote, whereas industrial applications may be assumed to take place within urban areas.

The apportionment of heavy industry (construction, mining) emissions, which comprises a significant portion of overall non-road diesel emissions, is more uncertain. Mining applications may take place at remote locations or may be conducted in close proximity to, or within, metropolitan areas.

Rather than provide a coarse estimate of the proportion of non-road diesel emissions likely to occur within urban areas options to more accurately consider urban and rural impacts are outlined in Section 9.

8.3 Emission Reductions given Compliance with Mandatory International Standards

Reference to US non-road diesel emission regulations was made due to these regulations having more comprehensive coverage of engine/equipment categories, thus allowing the evaluation of emission reductions achievable for a wider range of engines/equipment. Based on the emissions performance surveys conducted it was also evident that engines sold into Australia are also more likely to be referenced to US standards. Furthermore, US and EU standards are primarily aligned for a large proportion of non-road diesel engine/equipment power rating categories. Emission reductions were calculated taking into account the existing emission performance of new engines/equipment being imported into Australia as documented in **Section 5.5**.

Emission estimates for the controlled emission scenario by market segment, application (equipment type) and engine rating are given in **Appendix J**. Key results are presented and discussed in this subsection.

As discussed previously the controlled emission scenario is based on the assumption that engines meet US Tier 4 interim emission standards prior to 2015 and Tier 4 final standards post 2015 in line with US non-road diesel regulations. If emission standards are implemented locally, it is acknowledged that the compliance targets and timeframes are likely to be different. The controlled emission scenario assumed however provides an indication of the overall emission reductions achievable through the implementation of international best practice emission limits (with the broadest coverage) in the short- to medium-term.

8.3.1 Overall Controlled Scenario Emissions and Emission Reductions Achieved

Controlled emissions estimated for years 2020 and 2030 are presented in **Table 40** and **Table 41**, with the emission reductions achievable given. All other aspects of the projected engine/equipment population, other than the engine compliance status, are assumed to remain unchanged from the base case scenarios.

Annual PM_{10} emission reductions are estimated to be in the range of 5.6 ktpa to 10.2 ktpa in 2020, increasing to 7.3 ktpa to 14.1 ktpa by 2030.

Controls were estimated to result in annual NO_x emission reductions of between 44.1 ktpa and 65.6 ktpa by 2020, and in the range of 57.4 ktpa to 92.3 ktpa by 2030.

Table 40: Controlled scenario emissions from non-road diesel engines/equipment and estimated emission reduction achievable from Upper Bound base case emissions (2020)

Species	Controlled Emissions (tpa) (2020)	Emission Reduction (%) (2020)		Emission Reduction (tpa) (2020)	
		Based on Upper Bound Base Case Emissions	Based on Lower Bound (Best Case) Base Case Emissions	Based on Upper Bound Base Case Emissions	Based on Lower Bound (Best Case) Base Case Emissions
PM_{10}	989	91.2	85.0	10,222	5,613
$PM_{2.5}$	959	91.2	85.0	9,916	5,445
Total VOCs	3,355	63.2	63.7	5,750	5,878
NO_x	29,504	69.0	59.9	65,547	44,078
Benzene	67	63.2	39.0	115	43
Formaldehyde	396	63.2	39.0	679	254
Acetaldehyde	178	63.2	39.0	305	114
1,3-Butadiene	7	63.2	39.0	12	4
Acrolein	10	64.3	39.0	18	6

Engine/Equipment Population	454,281

Table 41: Controlled scenario emissions from non-road diesel engines/equipment and estimated emission reduction achievable from Upper Bound base case emissions (2030)

Species	Controlled Emissions (tpa) (2023)	Emission Reduction (%) (2030)		Emission Reduction (tpa) (2030)	
		Based on Upper Bound Base Case Emissions	Based on Lower Bound (Best Case) Base Case Emissions	Based on Upper Bound Base Case Emissions	Based on Lower Bound (Best Case) Base Case Emissions
PM_{10}	522	96.4	93.3	14,074	7,285
$PM_{2.5}$	506	96.4	93.3	13,652	7,067
Total VOCs	3,796	67.2	38.2	7,790	2,349
NO_x	25,169	78.6	69.5	92,246	57,387
Benzene	76	67.2	38.2	156	47
Formaldehyde	448	67.2	38.2	919	277
Acetaldehyde	201	67.2	38.2	413	124
1,3-Butadiene	8	67.2	38.2	16	5
Acrolein	11	68.3	38.2	24	7

Engine/Equipment Population	615,833

8.3.2 Emission Reductions by Market Segment and Equipment Type

Controlled scenario emissions and emission reductions achievable (based on the Upper Bound Base Case scenario by market segment for years 2020 and 2030 are presented in **Table 42** and **Table 43** respectively.

The contribution of emission reductions per market segment to overall emission reductions are illustrated for particulate emissions in **Figure 25**. The PM emission reductions reflect largely the contribution of market segments to base case emissions (as presented previously in **Figure 20**). The greatest emission reductions (55%) are achievable from Heavy Industry

(Construction, Mining), followed by Agriculture (25%), General Industry (13%) and Power Generation Sets (7%).

Table 42: Controlled scenario emissions from non-road diesel (2020)

Market Segment	Controlled Scenario Emissions (tpa) for 2020			
	PM_{10}	$PM_{2.5}$	Total VOCs	NO_x
Agricultural	44.8	43.5	509.58	1,178.6
Forestry	1.2	1.2	4.07	18.1
General Industrial	122.8	119.1	385.97	2,544.0
Heavy Industrial (Construction, Mining)	765.2	742.2	2,180.69	24,305.3
Lawn and Garden	0.6	0.6	8.70	17.4
Light Commercial	0.5	0.5	7.35	14.7
Marine	1.9	1.8	4.23	26.7
Power Generation Drive	6.7	6.5	42.22	152.6
Power Generation Sets	45.0	43.6	212.33	1,246.5
Total	988.6	959.0	3,355.1	29,504.0
Market Segment	Emission Reductions Achievable (tpa) for 2020, based on the Upper Bound Base Case Emissions Projected			
	PM_{10}	$PM_{2.5}$	Total VOCs	NO_x
Agricultural	2,139.2	2,075.0	1,345.4	15,479.3
Forestry	15.1	14.7	5.8	104.1
General Industrial	1,209.3	1,173.1	1,094.7	12,553.5
Heavy Industrial (Construction, Mining)	5,861.1	5,685.3	2,367.8	28,789.8
Lawn and Garden	24.2	23.5	22.5	249.3
Light Commercial	34.8	33.8	24.5	259.5
Marine	0.7	0.7	1.8	11.5
Power Generation Drive	80.2	77.8	84.7	1,130.0
Power Generation Sets	857.4	831.7	803.3	6,970.4
Total	10,222.2	9,915.5	5,750.3	65,547.4

Table 43: Controlled scenario emissions from non-road diesel (2030)

Market Segment	Controlled Scenario Emissions (tpa) for 2030			
	PM_{10}	$PM_{2.5}$	Total VOCs	NO_x
Agricultural	57.1	55.4	754.29	1,614.4
Forestry	0.2	0.2	3.79	7.6
General Industrial	83.7	81.2	469.77	2,307.1
Heavy Industrial (Construction, Mining)	338.4	328.3	2,263.01	20,124.9
Lawn and Garden	0.7	0.7	10.62	21.3
Light Commercial	0.7	0.7	10.43	20.9
Marine	2.9	2.8	6.39	41.0
Power Generation Drive	4.0	3.9	43.08	108.8
Power Generation Sets	34.3	33.3	234.74	923.5
Total	522.1	506.4	3,796.1	25,169.4
Market Segment	Emission Reductions Achievable (tpa) for 2030, based on the Upper Bound Base Case Emissions Projected			
	PM_{10}	$PM_{2.5}$	Total VOCs	NO_x
Agricultural	3,495.2	3,390.4	2,061.3	23,481.2
Forestry	16.1	15.6	6.1	114.6
General Industrial	1,784.4	1,730.8	1,552.3	17,854.9
Heavy Industrial (Construction, Mining)	7,664.4	7,434.5	3,137.8	40,589.7
Lawn and Garden	30.8	29.9	27.6	304.7
Light Commercial	55.0	53.4	36.8	371.4
Marine	1.2	1.1	2.4	17.1
Power Generation Drive	102.5	99.4	109.9	1,349.3
Power Generation Sets	924.8	897.0	855.5	8,162.8
Total	14,074.4	13,652.2	7,789.7	92,245.8

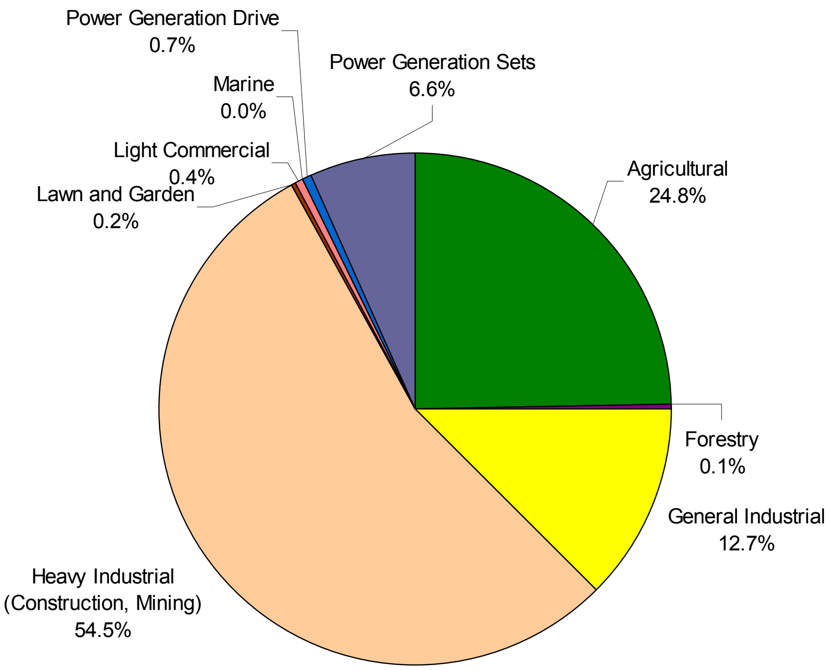

Figure 25: PM emission reductions by market segment projected for 2030, based on Upper Bound Base Case emission estimates

Particulate emission reductions by equipment type within the Heavy Industrial (Construction, Mining) and General Industrial segments similarly closely mirror the emission contributions of these equipment types as illustrated in **Figure 22** and **Figure 23**.

The most significant heavy industry equipment in terms of PM emissions and the potential for emission reductions (excluding miscellaneous equipment and loose engines) were identified to be off-highway trucks and excavators.

Agricultural tractors were estimated to account for over 80% of all agricultural sector PM emission reductions. Within the general industrial segment, miscellaneous loose diesel engines and pumps represent the most significant equipment types in terms of potential for emission reductions.

8.4 Prioritisation of Engine/Equipment Sub-populations

8.4.1 Prioritisation by Power Rating Class for Potential Regulation

Given that non-road engines may be manufactured for use in a range of non-road equipment and applications, the non-road diesel engines/equipment regulations are typically applicable across equipment types and applications but specified by power rating class. Prioritisation of power rating classes within the Australian context for potential regulation is therefore pertinent. The ranking of engine/equipment power rating classes on this basis is demonstrated in **Table 44**, based on particulate emissions / emission reductions.

Table 44: Ranking of non-road diesel power rating classes for potential regulation based on upper bound base case PM_{10} emissions and emission reductions achievable

Ranking	Power Rating Class (kW)	Total Upper Bound PM_{10} Base Case Emissions (tpa, 2030)	Total PM_{10} Emission Reductions (tpa, 2030)	Projected No. of Engines/Equipment by Power Rating Class
1	56 – 130	7,385	7,272	282,336
2	130 – 560	3,075	2,961	43,907
3	>560	2,428	2,179	8,464
4	37 – 56	786	760	54,101
5	19 – 37	595	581	80,499
6	8 – 19	308	301	123,942
7	<8	20	20	22,584
	Total	14,597	14,074	615,833

The most significant PM_{10} emission reduction is afforded through controlling engines in the 56 to 130 kW range (52% of total reduction estimated), followed by the 130 to 560 kW rating range (21%) and the greater than 560 kW engine class (16%). When considered in combination, the control of engines/equipment which have ratings greater than 56 kW are estimated to account for 88% of the overall PM emission reductions from the regulation of non-road diesel.

Small engines (less than 19 kW) are estimated to account for just over 2% of the overall PM emission reductions (i.e. 320 tpa), with very small engines (less than 8 kW) only responsible for 0.1% of the overall reductions (i.e. reduction of 20 tpa). A significant component of agricultural equipment sales are small engines less than 19kW.

8.4.2 Coverage of Emissions/Emission Reductions by International Regulations

Based on the assessment of US and EU non-road diesel engine regulations (see **Section 4.6**), US regulations were concluded to provide the broadest coverage (95%) in terms of the number of engines to which emission standards are applicable compared to the EU (30%). The greater coverage was primarily due to provision being made for the smallest engines within US non-road diesel engine regulation.

In terms of the percentage coverage of total emissions (and potential emission reductions achievable) from non-road diesel engine/equipment used in Australia, the coverage of base case emissions by US non-road diesel regulations are estimated to be >95%, with EU non-road diesel regulations covering about 80% of total non-road diesel engine/equipment emissions and emission reduction potentials.

8.4.3 Market Sub-sectors for Potential Non-regulatory Measures

Non-regulatory measures such as government-industry partnership programs typically require involvement of a relatively small number of companies, and the commitment and willingness of such industries to enter into a cooperative partnership with government.

The Heavy Industrial (Construction, Mining) Engines/Equipment and Power Generation Sets sub-sectors were identified for potential consideration for non-regulatory policy measures.

The introduction of effective emission reduction requirements within the Heavy Industrial (Construction, Mining) Engine/Equipment sub-sector was estimated to be able to achieve the most significant overall reduction in non-road diesel related PM_{10} emissions (i.e. 55% of total PM_{10} emission reductions achievable by implementing best practice emission standards).

8.5 Health Benefits of Emission Reductions

The accurate quantification of health and environmental impact potentials arising due to non-road diesel emissions would necessitate the compilation of detailed emission inventories, the simulation of resultant ambient air pollutant concentrations using air dispersion modelling, the characterisation of exposure potentials, and the application of applicable dose-response relationships. Costs related to modelled health and environmental impacts could then be estimated. Such ‘damage function’ modelling is not within the scope of the current study.

Reference is instead made to external (health) costs sourced from Coffey Geosciences (2003)[72], with costs adjusted for CPI to provide health costs for 2008 (**Table 45**). The unit costs given for PM_{10} and NO_x coincide with sources situated in urban areas. A portion of

72 Coffey Geosciences (2003). Fuel Quality and Vehicle Emission Standards Cost Benefit Analysis, Report prepared for the MVEC Review of Vehicle Emission and Fuel Standards Post 2006’ (released October 2003)..

non-road diesel emissions would coincide with lower exposure potentials. The range given in the table provides some indication of the magnitude of potential benefits of controlling non-road diesel emissions.

Table 45: Estimated environmental (health) benefits due to projected emission reductions for the non-road diesel sector

Air Pollutant	Unit External Cost (2008 AUD/tonne)(a)	Estimated annual health benefits, based on maximum non-road diesel controls implemented by 2030 (2008 AUD)
PM_{10}	$269,100/tonne	$2.0 to $3.8 billion
NO_X	$9,900/tonne	$0.6 to $0.9 billion

(a) Based on health cost estimates sourced from Coffey Geosciences (2003), with costs adjusted to 2008 dollar values.

8.6 Summary of Findings

Base Case Emissions:

- The total non-road diesel population (in terms of new and imported used engines/equipment sold into Australia after 2008) is estimated to be about 454,000 by 2020. This population is projected to increase to 616,000 by 2030, at which time post-2008 units will make up the bulk of the in-service population.

- Annual PM_{10} emissions due to non-road diesel engines/equipment were projected to be in the range of 7.8 ktpa to 14.6 ktpa by 2030 given base case (business as usual) operations, with 97% of such emissions being $PM_{2.5}$. Annual NO_x emissions are estimated to be in the range 82.6 ktpa to 117.4 ktpa by 2030.

- Heavy Industrial (construction, mining) Equipment is projected to contribute most significantly to non-road diesel emissions, representing over 50% of PM_{10}, $PM_{2.5}$ and NO_x emissions and 45% of VOC emissions by 2030.

- General Industrial Equipment accounts for 13% of PM and 17% of total VOCs and NO_x emissions in 2030. Miscellaneous loose diesel engines and pumps represent the most significant contributors.

- Agricultural Equipment accounts for 24% of PM emissions by 2030.

- Power Generation Equipment account for 7% of PM and NO_x emissions in 2030.

- Equipment within other market segments (foresty, lawn and garden, light commercial, marine) represent more minor sources, with combined PM emissions of less than 1% of total non-road diesel PM emissions.

- Equipment which have ratings greater than 56 kW account for 88% of total PM emissions, despite only accounting for about 50% of the total number of engines.

- Small engines (below 19 kW) are estimated to contribute about 2% of total PM emissions, despite accounting for almost a quarter of the total number of engines. A significant component of agricultural equipment sales comprise small engines, less than 19kW.

Emission Reduction Achievable Given Compliance with International Standards:

- Given stringent controls (i.e. implementation of US Tier 4 emission standards), annual PM_{10} emission reductions are estimated to be in the range of 5.6 ktpa to 10.2 ktpa in 2020, increasing to 7.3 ktpa to 14.1 ktpa by 2030.
- Controls were estimated to result in annual NO_x emission reductions of between 44.1 ktpa and 65.6 ktpa by 2020, and in the range of 57.4 ktpa to 92.3 ktpa by 2030.
- The greatest PM emission reductions are achievable from Heavy Industry (Construction, Mining) (55%), followed by Agriculture (25%), General Industry (13%) and Power Generation Sets (7%).
- The control of larger (above 56 kW) engines/equipment accounts for 88% of the overall potential PM emission reductions from non-road diesel sector.
- Small engines (below 19 kW) are estimated to account for about 2% of the overall PM emission reductions (i.e. 320 tpa reduction), with very small engines (below 8 kW) responsible for 0.1% of the overall reductions (i.e. reduction of 20 tpa).

Prioritisation by Power Rating Class for Potential Regulation:

Non-road engines may be manufactured for use in a range of non-road equipment and applications, prioritisation of power rating classes within the Australian context for potential regulation is therefore pertinent. Based on the extent of PM emission reductions achievable, the predefined power rating classes were ranked as follows (from highest to lowest priority, with percentage of total PM_{10} emission reduction achievable noted):

Ranking	Power Rating Class (kW)	% of Total PM_{10} Emission Reductions
1	56 – 130	51.7
2	130 – 560	21.0
3	>560	15.5
4	37 – 56	5.4
5	19 – 37	4.1
6	8 – 19	2.1
7	<8	0.1

Market Sub-sectors for Potential Non-regulatory Measures

- Two market sub-sectors were identified for consideration for potential implementation of non-regulatory measures based on the particulate emission reductions achievable, namely Heavy Industrial (Construction, Mining) Engines/Equipment and Power Generation Sets.

- The introduction of effective emission reduction requirements within the Heavy Industrial (Construction, Mining) Engine/Equipment sub-sector was estimated to be able to achieve the most significant overall reduction in non-road diesel related PM_{10} emissions (i.e. 55% of total PM_{10} emission reduction achievable).

Environmental (Health) Benefits of Emission Reductions

- Taking into account emission reductions projected given compliance with best practice emission standards, and published unit external costs for NO_x and PM_{10}, estimated annual environmental (health) benefits are in the range $2.5 to $4.7 billion (2008 AUD) by 2030.

9 Emission Management Options for Australia

This Section presents a preliminary, qualitative assessment of the applicability, within the Australian context, of identified non-road diesel emission reduction measures and product sub-populations targeted by such measures abroad. The information presented in Sections 7 and 8 provides the basis for the assessment.

Factors taken into account in the assessment include:

- emission reductions achievable given compliance of new and used engines/equipment sold into the Australian market with best practice emission limits (projected for 20 years by product sub-population) (Section 8);
- approximate cost of the measure, and its efficiency (cost vs benefit) relative to other measures;
- administrative ease of the measure;
- stakeholder readiness;
- urban/rural impacts of the measure; and
- consideration of any possible additional benefits e.g. increased fuel efficiency / reduced greenhouse gas emissions.

In the current assessment of product-based emission reduction measures it will be assumed that such measures are complimented by appropriate fuel quality requirements, in line with international trends documented in Section 7.

9.1 'Business as Usual' (No Action by Government)

Prior to the assessment of emission reduction measures it is pertinent to consider the 'business as usual' option. This option comprises no action being taken by government, with the outcomes of such inaction being considered.

Nationally, non-road diesel engines are estimated to contribute higher PM_{10} emissions compared to the on-road vehicles sector which has been subject to increasingly stringent regulation. Non-road diesel emissions are also expected to increase in coming years given: projected increases in ADO consumption[(73)], increases in non-road diesel engine/equipment sales (see **Section 5.4.6**), and potentially the increased use of off-specification fuels within the non-road transport sector.

Furthermore, the number of 'dirtier' engines and equipment being sold into Australia may increase as other countries introduce or tighten regulations and engine/equipment manufacturers seek alternative markets. Used engines/equipment were inventoried to have a minor market share in 2008. It is however postulated by some industrial representatives

73 ABARE (2009). Energy in Australia 2009, Australian Government Department of Resources, Energy and Tourism.

that there will be a significant increase in the market for used equipment with poorer emission performances if non-road diesel controls are not implemented in future years. Due to information constraints the impact of increased uptake of 'dirtier' used engines/equipment could not be quantitatively assessed during the current study, with the upper bound base case projections assuming the persistence of engine/equipment emission performances (as inventoried for 2008).

Some industry players promote the use of engines with improved emissions performance. Support for the uptake of cleaner technologies was also noted to take place collectively, with CMEIG encouraging progress towards Tier 3 / Stage IIIa compliant construction and mining equipment over the past few years. Such actions by industry will partly offset future increases in non-road diesel emissions.

Given the significance of non-road diesel emissions, anticipated increases in the extent of such emissions given 'business as usual', and the risk of additional uptake of 'dirtier' engines/equipment, inaction by government is not considered beneficial.

9.2 Product-based Emission Reduction Measures

Product-based measures range from mandatory requirements to voluntary measures, and from measures with broad coverage across engine/equipment sub-populations to more specific measures targeting prioritised sub-populations.

Non-road diesel standards tend to have relatively broad coverage in terms of the engine sizes and market segments covered. Some regulatory and alternative measures may however focus on specific niche product types, based on an identified engine range, market segment and/or application considered worthy of management.

The main characteristics and applicability of a range of product-based emission reduction measures are considered in subsequent subsections.

9.2.1 Option 1 - Explicit Government Regulation

This option is characterised by the adoption of mandatory best practice standards for non-road diesel engines/equipment, with legally binding standards and mechanisms for non-compliance.

Explicit government regulation are more likely to lead to the maximum achievable reductions in emissions, as compared to non-regulatory measures.

Achievable Urban Emission Reductions

Achievable urban emission reductions and associated health benefits are largely dependent on:

- the coverage of the regulations, in terms of the engine sub-populations covered by the regulation,
- the urban/rural location of covered engine sub-populations, and

- the specified emission limits.

To maximise the efficiency of regulations, and given that the same diesel engines are used in equipment and vehicles implemented within several market segments, non-road diesel regulations are typically applicable across equipment types/applications but specified by power rating class. Engine power rating ranges covered by non-road diesel regulations abroad are summarised as follows:

<8 kW	US; Canada; China; India
8 – 19 kW	US; Canada; China; India (being considered by EU)
19 – 560 kW (various bands)	US; Canada; China; India; EU; Japan
>560 kW	US; Canada; (being considered by EU)

Although EU non-road diesel regulations currently exclude engine power classes below 19 kW and above 560 kW, it has been proposed that the regulations be revised to include 8 to 18 kW and greater than 560 kW engines. This recommendation is supported by conclusions from the assessment of compliance costs, socio-economic impacts, environmental impacts and efficiency (costs versus benefits). It is notable that 0-8 kW engines were estimated to contribute only 0.1% of PM and 0.04% of total NO_X emissions respectively(74). Based on a cost-benefit analysis, the inclusion of these engines within regulations were concluded to be unjustified(75).

In the impact assessment study for the EU Directive review reference was made to industry claims that it is very challenging to make small (0-8 kW) engines comply with US emission standards. This view is shared by suppliers of small diesel engines into the Australian market. It was also noted in the EU review that regulation of these engines could result in their being replaced by 4 stroke spark-ignition engines.

Based on the extent of PM emission reductions achievable through the implementation of best practice emission standards within Australia (by 2030), power rating classes may be prioritised as follows:

Ranking	Power Rating Class (kW)	Projected No. of Post-2007 Engines/Equipment by Power Rating Class (2030)	Upper Bound PM_{10} Emission Reductions (tpa, 2030)	% of Total PM_{10} Emission Reductions
1 (highest priority)	56 - 130	282,336	7,272	51.7
2	130 - 560	43,907	2,961	21.0
3	>560	8,464	2,179	15.5
4	37 - 56	54,101	760	5.4
5	19 - 37	80,499	581	4.1
6	8 – 19	123,942	301	2.1
7 (lowest priority)	<8	22,584	20	0.1
Total	All Classes	615,833	14,074	100%

74 Krasenbrink A and Dobranskyte-Niskota AD (2007). 2007 Technical Review of the NRMM Directive 1997/68/EC as amended by Directives 2002/88/EC and 2004/26/EC, Draft Final Report, European Commission, Institute for Environment and Sustainability.
75 Van Zeebroeck B, Vanhove F and Franckx L (2009). Impact Assessment Study – Reviewing Directive 97/68/EC – Emissions from non-road mobile machinery, Final Report, European Commission, 30 January 2009.

The most significant emission reduction could be achieved through the implementation of emission control measures for engines in the 56 to 130 kW range (52%), followed by the 130 to 560 kW rating range (21%) and the large (>560 kW) engine class (16%). When considered in combination, the control of engines/equipment which have ratings >56 kW are estimated to account for 88% of the overall PM emission reductions from the regulation of non-road diesel (i.e. reduction of 7.3 ktpa to 14.1 ktpa by 2030).

Small engines (less than 19 kW) are estimated to account for 2.1% of the overall PM emission reductions. Similar to engine power rating class contributions estimated for the EU, very small engines (below 8 kW) were only estimated to be responsible for 0.1% of the overall reductions in PM_{10} emissions for Australia (i.e. reduction of up to 20 tpa).

Air pollutants released within urban areas have greater impact potentials due to a higher exposure potentials and the likelihood of cumulative pollution concentrations due to the colocation of sources. Insufficient information was available to quantify the extent of non-road diesel emissions occuring in urban areas. It is however noted that a large portion of small engines (below 8 kW) are used in agricultural applications which are likely to be conducted at more remote locations.

Cost Efficiency of Regulations

Costs related to the development and implementation of emission standards based regulations and an achievement of compliance include:

- Costs of purchasing cleaner engine technologies to reduce emissions, borne by industry. Broader impacts on industry are limited as almost all non-road engines are imported.
- Costs of adopting appropriate overseas standards, borne by government.
- Costs of enforcement, borne by government.

The costs to industry are expected to be passed on, either entirely or in part, to consumers. Further costs relate to fuel quality management measures which are needed to ensure compliance and/or support the implementation of advanced exhaust treatment technologies.

The quantification of costs related to the development and implementation of emission regulations and achievement of compliance with such regulations was not quantifiable during the current study. It is however noted that PAE (2005) previously estimated the costs of implementing explicit government regulation across all non-road engines and equipment (covering all fuel types including petrol and diesel) to be about $2.1 billion[(76)].

Benefits include direct health benefits due to reduced exposures to air pollutant concentrations (including occupational and public exposures) and broader benefits associated with reductions in environmental damages.

76 PAE (2005). Management Options for Non-road Engine Emissions in Urban Areas, Report compiled by Pacific Air and Environment on behalf of the Department of the Environment and Heritage, November 2005.

Emission reductions achievable through the implementation of best practice international emission standards for non-road diesel engines were estimated to result in monetary benefits in the range of $2.5 to $4.7 billion per annum by 2030 due to reduced health (**Section 8.5**).

To provide further comparisons of the costs and benefits of non-road diesel emission management and assess the cost-effectiveness of non-road diesel regulations reference is made to more rigorous cost-benefit studies undertaken in the US and Europe (**Table 46**). Costs generally reflect aggregated incremental fuel costs (where applicable), costs for producing compliant engines/equipment and operating costs.

A further, more recent cost benefit analysis of non-road diesel emission measures is provided in the regulatory impact assessment for the EU Directive review (Zeebroeck and Vanhove, 2009). Costs and benefits arising due to greater than 560 kW engines being brought into compliance with US Tier 4 emission standards were evaluated(77). Estimated benefits (in terms of reduced damages) were estimated to exceed overall costs by a factor of 12.2, with overall gains of EUR4,300 million estimated for the 2008 to 2030 period. Gains of EUR650 million were similarly projected as a result of the introduction of Tier 4 emission standards for 8 to 19 kW engines.

The cost-effectiveness of regulating non-road diesel engines has been found to compare favourably with other measures in the US, including bus retrofitting, heavy-duty highway diesel emission standards (on-road), and non-road heavy duty diesel engine retrofits (**Table** 47). The costs of retrofitting in-service non-road diesel engines are significantly higher than those established for the Non-road Tier 4 emission standards (by factors of between 1.7 and 7.8 for PM reductions and between 1.9 and 19 for NOx reductions).

77 Externality costs for Europe are provided in the European Handbook on External Costs (CE Delft, 2008). The externality costs of PM is estimated at EUR30,625/ton PM, with the major part of this cost accounting for health risks for the machinery user. In addition to the valuation of health impacts (due to inhalation exposures) the external costs also account for crop damage, material damage and negative consequences for biodiversity (CE Delft, 2008). External costs of EUR1,171/ton HC and EU5,155/ton NOx are also specified.

Table 46: Cost-effectiveness of US and EU non-road diesel engine regulations				
Emission Standard	Costs of Achieving Emission Reductions		Benefits of Reduction	Source
	PM Cost Effectiveness	NOx / NMHC + NOx Cost Effectiveness		
US Tier 1 - 3	<US$2,500/ton(a)	<US$550/ton NMHC + NOx		US EPA, 1998[78]
US Tier 4 (from base of Tier 2 / Tier 3; including fuel costs)	US$11,200/ton	$US1,010/ton NMHC + NOx	Total benefits ($80 billion) concluded to outweigh costs ($2 billion) by 40 to 1.	US EPA, 2004[79]
Stage IIIA	£1,010 – 1,930/tonne	£850 – 1,620/tonne NOx	Central high estimate for transport: £59,230/tonne PM £1,098/tonne NOx Benefits concluded to outweigh costs.	UK DfT, 2006[80]
Stage IIIB	£6,800 – 12,900/tonne	£750 -1,430/tonne NOx		UK DfT, 2006
Stage IIIB including fuel cost	£19,800 – 37,700/tonne	£750 – 1,430/tonne NOx		UK DfT, 2006
Stage IV	£6,800 – 12,900/tonne	£820 -1,560/tonne NOx		UK DfT, 2006
Stage IV including fuel cost	£19,800 – 37,700/tonne	£820 – 1,560/tonne NOx		UK DfT, 2006

(a) Annualised 2004-2036 costs representing net present values at 3% discount rate.

Table 47: Comparison of the control efficiency of US non-road diesel regulations with other initiatives		
Non-road Tier 4 emission standards (costs in US$)	Other Initiatives (costs in US$):	
$11,200/ton PM	Retrofitting School Buses and Class 6-8c Trucks	$11,000 – $69,900/ton PM
	Urban Bust Retrofit and Rebuild program	$31,500/ton PM
	2007 Heavy-Duty Highway diesel emission standards (on road)	$14,200/ton PM
	Heavy-Duty Non-road Diesel Engine Retrofits	$18,700 – $87,600/ton PM reduction
$1,000/ton NO_x	2007 Heavy-Duty Highway diesel emission standards (on road)	$2,100/ton NO_x
	Heavy-Duty Non-road Diesel Engine Retrofits	$1,900 - $19,000/ton NO_x

Source: US-EPA (2007). Diesel Retrofit Technology, An Analysis of the Cost-Effectiveness of Reducing Particulate Matter and Nitrogen Oxides Emissions from Heavy-Duty Non-road Diesel Engines Through Retrofits, Office of Transportation and Air Quality, Report No. EPA420-R-07-005, May 2007

Cost Sensitivity

The most price sensitive non-road market segments, both locally and abroad, are considered to be the agricultural segment where cost containment is a high priority and the medium construction equipment sector where equipment is smaller and there are a number of owner/operators in small business operating environments.

Sectors which are arguably more flexible relative to absorbing costs are the airport service equipment, heavy construction equipment, industrial and stationary power generation sctors.

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78 US-EPA (1998). Final Regulatory Impact Analysis: Control of Emissions from Non-road Diesel Engines, United States Environmental Protection Agency, Report No. EPA420-R-98-016, August 1998.
79 US-EPA (2004). Final Regulatory Analysis: Control of Emissions from Non-road Diesel Engines, EPA-420-R-04-007, May 2004.
80 UK Department of Transport (2006) Regulatory Impact Assessment on NRMM Emissions, www.dft.gov.uk/consultations/aboutia/ria/nrmmemissions?page=3.

The design features and greater cost sensitivity of small engines have been noted to constrain the targeted level of emission control in the US, with these engines being subject to less stringent emission standards compared to larger engines. Technological and cost constraints are also cited as reasons for not stipulating EU emission standards for small engines (below 8 kW).

Fuel Efficiency

The impact of new emission standards on energy (and greenhouse gas emissions) is a function of the effect of such standards on fuel consumption from complying engines.

Fuel consumption rates are significantly affected by engine emission regulations. Overall, based on the US experience, there has been a slight, overall improvement in fuel consumption across the progressive implementation of emission reduction tiers. This fuel economy improvement was most pronounced during the latter half of the 1990s when the first emission regulations came into effect.

The redesign of combustion chambers, incorporation of impoved fuel injection systems and introduction of electronic controls are significant measures in terms of improving fuel efficiency(81).

Shorter-term trends in fuel efficiency are however noted to have varied between individual emission reduction stages (i.e. moving from Tier 1 to Tier 2, Tier 2 to Tier 3, Tier 2 to Tier 4 or Tier 3 to Tier 4). Some technology changes have the potential to reduce fuel consumption as well as emissions. One major engine manufacturer notes that Stage 3A/Tier 3 engines had poorer fuel efficiencies due to these engines using internal exhaust gas recirculation (EGR) to reduce NO_x emissions. EGR adversely affects fuel consumption, resulting in a 3% to 5% increase in fuel consumption rates. Stage 2 / Tier 2 and Stage 3B / Tier 4i engines are however fairly equivalent in their fuel efficiency.

Administrative Ease of Implementation

The implementation of non-road diesel product emission standards by individual states is unlikely as such regulations would be inconsistent with the 1992 Intergovernmental Agreement on Environment signed by the Commonwealth, States and Teritories and with existing Commonwealth and State Government mutual recogition legislation.

State-based regulations would also be problematic in terms of enforcement. Under the Commonwealth Mutual Recognition Act 1992 and the Trans-Tasman Mutual Recognition Act 1997, products imported into (or produced in) an Australian State or Territory or New Zealand and which can be sold lawfully in that jurisdiction, can be sold freely elsewhere even if the products do not comply with the regulatory standards of the other jurisdiction(s).

National Environment Protection Measures (NEPMs), which each state incorporates into state legislation provide a further mechanism for potential national non-road diesel regulations. Under the NEPM option jurisdictions may also decide to provide different penalty and enforcement regimes resulting in lower penalties and varying levels of

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81 US-EPA (2004). Final Regulatory Analysis: Control of Emissions from Non-road Diesel Engines, EPA-420-R-04-007, May 2004.

enforcement in some jurisdictions. This could reduce the overall effectiveness of the NEPM option and also provide a lack of consistency to industry.

Compliance promotion activities could include mail out of the final regulations, development and distribution of promotional materials (e.g. fact sheets, web material), advertising in trade and associated magazines, attending trade association conferences, and presenting workshops and information sessions to explain the regulations. It may also include responding to and tracking enquiries.

Enforcement activities typically include the delivery of training, inspections, investigations, and implementation of measures to deal with alleged violations.

Technological Feasibility of Complying with Best Practice Standards

Given that non-road diesel engines are primarily imported into Australia, and that internationally engines have been developed to meet international best practice emissions standards, technological feasibility is broadly assumed in the current study.

A detailed assessment of technological feasibility, taking into account local circumstances and applications, will be required in the event that implementation of emission standards is contemplated. Particular attention should be paid to the technological (and economic) feasibility of regulating very small (less than 8 kW) engines, should such engines be considered for inclusion.

Regulatory Approach

A range of regulatory approaches may be considered including:

- Establishment of single emission standards by power rating class (as is the international norm);
- Implementation of tiered benchmarks using a ‘star’ type rating system. Such a system could include: minimum emissions performance standards (or alternatively disendorsement labels), and could be supported by product labelling and a possible web database.

The single emission standard would remove all high emission engines from sale, and provide consumers with confidence that all products met certain emission standards. The tiered ‘star’ system approach would reward products achieving more stringent overseas standards, whilst potentially ensuring that minimum emission performance standards are met.

Given that non-road diesel engines are primarily imported, the inclusion of additional labelling to facilitate a tiered ‘star’ type rating system could be troublesome for engine manufacturers/suppliers.

Stakeholder Readiness

Based on the survey of large non-road diesel equipment users undertaken during this study, as documented in Section 6, it was concluded that companies surveyed are generally open to cleaner non-road diesel alternatives. Companies surveyed tended to support either a combination of guidelines, improved information and financial incentives, or the use of mandatory measures, either in isolation or in addition to improved information and financial incentives.

A portion of non-road diesel engine/equipment suppliers to the Australian market currently offer units which comply with various international standards (see Section 5.5). Emission compliance figures and consultation with industry stakeholders suggests potential support for broader, industry-wide compliance able to provide a level-playing field.

Non-road diesel engine/equipment emission standards are implemented across various Asian, North American and European countries. Given that many of the brands being marketed within Australia are manufactured within such countries, it is envisaged that cleaner technologies could readily be sourced and imported.

Stakeholder Inputs

Based on industry consultations undertaken as part of the study, one large non-road diesel engine/equipment supplier was identified as being strongly in support of a regulatory framework in Australia that harmonises with, and full accepts US and/or EU certified products. The supplier further recommends that Australia consider adopting a US Tier 2 / EU Stage II emission standards as soon as practical for non-road diesel equipment, subsequently working with industry towards more stringent standards. The supplier indicated its willingness to support such a regulatory process.

It is speculated by several suppliers that the number of ‘dirtier’ engines and equipment being sold into Australia may increase as other countries introduce or tighten regulations and engine/equipment manufacturers seek alternative markets.

Concerns are raised regarding the costs of compliance for small engines (below 16 kW), and specifically engines used within agricultural applications. It is noted that the cost of modifications to ensure compliance may far outweigh the cost of the base unit in some instances, and that this may increase the purchase of used non-compliant imports.

The current study focused on smaller marine engines, below 37 kW, which are typically included in non-road diesel regulations abroad. Several non-road diesel engine suppliers emphasised the need to consider the regulation of marine engines above 37 kW. Larger engines are regulated under specific marine engine rulemaking in the US.

Several non-road diesel engine suppliers have emphasised the importance of fuel quality. If off-specification diesel fuel (with higher sulfur content) remains commercially available for non-road applications, it will have a significant negative impact on engines equipped with after treatment and engines using oils which are not developed for elevated fuel sulfur operation.

Other views expressed by non-road diesel engine/equipment suppliers are as follows:

- The Australian non-road diesel market is comparatively small and engines are primarily sourced from abroad. Acceptance of products which comply with emission standards within other countries, or harmonisation of Australian standards with those of other countries, is therefore advocated.

- Engine maintenance is a major factor in ensuring continued compliance, with the emission compliance of cleaner technologies being compromised by modifications or poor maintenance.

9.2.2 Option 2 - Co-regulation

Co-regulation is similar to explicit government regulation, except that it involves a greater element of involvement from industry. Typically, the relevant peak industry bodies (e.g. CMEIG, TMA, ADEDA) would be engaged to outline the need for emission abatement, to offer support to industry, and to highlight that lack of industry action may lead to further regulation.

Industry then undertakes internal consultation to identify acceptable standards, compliance testing requirements and enforcement measures, industry code of practice and any requirements for a phase-in period.

Outcomes of government consultation with regulatory and community stakeholders are incorporated and consensus is reached between government and industry on emission standards to be met by non-road diesel engines/equipment.

The peak industry bodies adopt the agreed limits and associated processes. An agreement is signed between the relevant government agency and peak industry bodies. The agreement is certified and enforcement is undertaken by government as for explicit government regulation.

Administrative Ease of Implementation

To be successful co-regulatory and non-regulatory measures such as government-industry partnership programs typically require involvement of a relatively small number of companies, and the commitment and willingness of such industries to enter into a cooperative partnership with government.

Australian examples of co-regulation include the Green Vehicle Guide and the Packaging Covenant. In the case of the Green Vehicle Guide, an industry-government agreement exists whereby industry reports test results to government in an agreed format within a specified timeframe. Government manages the data and promotes the program.

The non-road diesel sector is diverse ranging from small suppliers of small agricultural pumps to significant suppliers of large construction equipment and gen sets. The sector includes loose engines and assembled equipment, with engines/equipment being sold into a wide range of markets (agricultural, construction, industrial, forestry, etc.). It is therefore not surprising that at least three industry bodies have been formed to represent the diverging interests of engine/equipment suppliers - namely the Australian Diesel Engine Distributors Association (ADEDA); the Construction and Mining Equipment Industry Group (CMEIG); and the Tractor and Machinery Association of Australia (TMA). Furthermore, it is noted that a number of non-road diesel engine/equipment suppliers, including some companies with significant market share, are not members of these associations.

The large number of distributors to the Australian market, and range of industry bodies, is likely to complicate the establishment of an agreement by industry and government in regard to emission standards to be realised.

Considering the complexity of negotiating an agreement to cover all non-road diesel engines/equipment, it is recommended that the selection of a product sub-population for potential co-regulation be considered.

Product Sub-populations for Potential Targeting and Resultant Emission Reductions

Two market sub-sectors have been identified for potential consideration in terms of co-regulatory and non-regulatory measures, based on the profile of product suppliers and the particulate and NO_x emission reductions achievable:

- Heavy Industrial (Construction, Mining) Engines/Equipment
- Power Generation Sets

The overall PM_{10} emission reduction achievable (by 2030) through controlling these sub-populations are estimated to be as follows:

Market Sub-sector	Power Rating Class	Upper Bound PM_{10} Emission Reductions Achievable (2030)	% of Total Emission Reductions	No. of Engines/Equipment (2030)	PM_{10} Emission Reductions (kg/unit/annum)
Heavy Industrial (Construction, Mining) Engines/Equipment	All	7,664	54.5	138,088	56
	>19 kW	7,617	54.1	129,457	59
	>37 kW	7,330	52.1	108,312	68
	>56 kW	6,948	49.4	79,794	87
Power Generation (Gen Sets and Drives)	All	1,027	7.3	54,956	19
	>19 kW	893	6.3	11,441	78
	>37 kW	870	6.2	7,580	115
	>56 kW	783	5.6	4,912	159

The introduction of effective emission reduction requirements within the Heavy Industrial (Construction, Mining) Engine/Equipment sub-sector was estimated to be able to achieve the most significant overall reduction in non-road diesel related PM_{10} emissions.

Per unit emission reductions were significantly greater for larger engine sizes. Emission standards could potentially be initially negotiated for larger (above 37 kW) engines/equipment, thus reducing the number of units being regulated without substantially affecting the emission reduction achievable.

The implementation of co-regulatory / non-regulatory emission reduction measures for Heavy Industry (Construction, Mining) Equipment is made more feasible by the existence of CMEIG which covers a substantial portion of suppliers of such equipment. Furthermore, it is noted that CMEIG has supported progress towards the adoption of Tier 3 / Stage IIIa engines in Australia. Such progress is evident in the emission performance information collated for heavy industrial (construction, mining) equipment. It is however noted that CMEIG membership currently does not cover all heavy industry equipment suppliers, with at least one industry with significant market share not being affiliated with the industry group.

Technological Feasibility, Cost Efficiency, Cost Sensitivity, Fuel Efficiency

As outlined for Option 1 – Explicit Government Regulation, in terms of broad coverage of the non-road diesel sector.

Given the engine/equipment sub-populations recommended for consideration for co-regulation or non-regulatory measures, it is expected that technological feasibility and cost efficiency will be enhanced and cost sensitivity reduced. The impact on fuel efficiency will need to be assessed in consultation with stakeholders to ensure fuel use and costs are minimised and associated greenhouse gas emissions mitigated.

9.2.3 Option 3 - Quasi-regulation

Typically a code of practice including emission limits would be developed through government-industry consultation, with this code being endorsed and implemented by industry. Government however does not register or certify the industry agreement (e.g. Memorandum of Understanding) and therefore has no statutory force for standards. No enforcement is undertaken.

As for co-regulation and other non-regulatory measures, this option is unlikely to be successful if broad coverage of the non-road diesel sector is contemplated.

The most suitable approach would be to target a viable sub-population, as outlined previously under co-regulation. In addition to the heavy industry equipment and power generation set sectors, suppliers of loose diesel engines could possibly be targeted for a Memorandum of Understanding via ADEDA. It is however noted that loose diesel engine suppliers serve a diverse range of markets and therefore have a wide range of interests which may add to the challenge of gaining industry consensus. Furthermore, ADEDA's membership currently does not include all industries with significant market share.

Non-regulatory measures are noted to be significantly less likely to lead to the maximum achievable reductions in emissions, but may be effective on a sub-population basis.

9.2.4 Option 4 - Self-regulation

Self-regulatory measures range from voluntary compliance with emission limits (within or outside of recognition programs) to industry benchmarking initiatives.

A code of practice covering non-road diesel equipment could be developed with emission limits based on either industry approved levels, current best technology, standards developed by Standards Australia or on standards from abroad (US, EU). In the case of recognition programs, emission limits are more likely to be set in line with international best practice / current best technology. Industry would need to undertake compliance monitoring and demonstration in order to achieve recognition under the program.

For industry benchmarking, emissions performance information is collated across industry providers and made public (e.g. web-based data base) to facilitate industry benchmarking. Given the complexity of collating emission performance information from engine/equipment suppliers during the current study, and considering that such information was classified as confidential by most companies, an industry benchmarking initiative is unlikely to be successful without substantial further cooperation by industry.

Self-regulation is significantly less likely than regulation and co-regulation to achieve the maximum emission reductions projected.

9.3 Fuel Quality Management

The extent and composition of diesel exhaust emissions is not only dependent on the emission performance of engines and equipment but also on operational factors and fuel composition. Given the significant influence fuel composition has on engine design, operation and emissions, it is not surprising that the management of fuel quality is being incorporated into diesel equipment emission management measures, e.g. US Clean Diesel Rule passed in 2004.

In Australia, Commonwealth Fuel Quality Standards mandate fuel quality for various fuels including automotive diesel. The Fuel Standard (Automotive Diesel) Determination 2001, incorporating the Fuel Standard (Automotive Diesel) Amendment Determination 2009 (No. 1), specifies requirements to be met by diesel including sulfur content. The sulfur content of diesel has been regulated down from 500 ppm to 50 ppm, and most recently to 10 ppm.

The fuel standard for diesel holds relevance given that non-road engines and equipment may be powered by fuels bought from the major fuel retailers which therefore comply with the national fuel standards. It is however noted that ADO meeting the Fuel Standard is not required by law to be used for non-road diesel engines/equipment. Some non-road engines/equipment may be operating using fuels that do not meet the standard. There is also the potential for increased use of off-specification fuels within the non-road transport sector for reasons discussed previously.

Internationally the trend has been towards the use of product-based and fuel quality related measures in combination to more efficiently and cost-effectively reduce emissions from the non-road diesel sector. The incorporation of sulfur-sensitive control technologies such as catalytic particulate filters and NOx adsorbers in engines to meet higher order (Tier 4, Stage IIIb) standards has also necessitated reductions of sulfur content in non-road diesel fuels.

Mandatory environmental fuel specifications are introduced by EU Directives. The EU diesel fuel specification *2009.01* sets a maximum sulfur limit of 10 ppm (“sulfur-free”) for diesel fuel for both highway and non-road vehicles.

Fuel quality is regulated by the US EPA under the authority of the Clean Air Act. Historically the sulfur content in diesel fuels for highway and non-road vehicles was limited to 0.5% (wt.). Diesel Fuels have since been regulated to 500 ppm in June 2007 for non-road fuels, and are scheduled to be reduced to 15 ppm (termed ultra low sulfur diesel, ULSD), effective June

2010. ULSD has been legislated for non-road engines to enable advanced emission control systems to comply with the Tier 4 non-road emission standards.

9.4 Preferred Approach

Nationally, non-road diesel engines are estimated to contribute PM_{10} emissions and significant NO_x emissions of a similar magnitude compared to the on-road (petrol and diesel) vehicle sector which has been subject to increasingly stringent regulation. Given the estimated significance of non-road diesel engine/equipment emissions, and projected increases in the extent of such emissions given 'business as usual', ongoing inaction by government is not advised.

Next Steps

The establishment of national non-road diesel regulations based on existing overeseas standards is the preferred approach to effectively address emissions from this sector. Consideration of Australian non-road diesel emissions regulations would require a regulatory impact assessment be conducted, which includes a detailed cost benefit analysis to assess the merits of regulation and involve thorough stakeholder consultation on possible options.

The cost benefit analysis should include the consideration of energy efficiency impacts of any proposed standards in consultation with stakeholders to ensure fuel use and costs are minimised and associated greenhouse gas emissions mitigated.

In line with international trends, any such regulations should specify emission standards by engine rating class and have broad coverage, including as a minimum engines/equipment with 19 kW to greater than 560 kW power ratings.

Urban/Rural emissions

Given that the specific locations of engine/equipment applications are not known it is important that the cost benefit analysis consider urban and rural impacts. Options that could be considered in the cost benefit analysis include:

- Excluding small engines i.e. 0 to 8 kW engines and consideration of excluding engines/equipment in the 8 to 19 kW. A significant proportion of agricultural equipment falls into these categories. The smallest engines (less than 8 kW) are estimated to contribute less than 0.1% of total PM emissions and engines less than 19 kW are estimated to account for just over 2%. Agricultural pumps and irrigation applications are dominated by small engines (76% less than 8 kW; 80% less than 19 kW). The average power rating of agricultural tractors sold is of the order of 60 kW, with about 20% of tractors being smaller than 19 kW.

- Excluding all agricultural tractors as generally agricultural applications take place in remote areas. (Note any loose engines later installed in tractors may not be covered by this option).

- Impacts on the mining sector could also be considered. As mining applications can take place at remote locations or conducted in close proximity to metropolitan areas. However, given the high level of compliance of mining engines and equipment with an existing US or EU standard it is likely the sector would experience minimal impacts from formal adoption of emission standards given the phasing in of such standards.

Harmonization with US and EU emissions limits

It is recommended that any proposed non-road diesel regulations be harmonised with US and EU regulations in terms of engine rating classes, emission standards and compliance testing protocols. Compliance timeframes should however be tailored to reflect local circumstances, with progressive implementation of more stringent emission limits to minimise potential economic impacts and maximise compliance with regulations. Maximum emission reductions achievable were demonstrated during the current study by assuming compliance with Tier 4 standards in the short- to medium-terms. It is however advised that less stringent standards be considered in the short-term and progression proposed towards the adoption of more stringent standards (e.g. implementation of Tier 2 equivalent standards by 2012, Tier 3 equivalent standards by 2020, and Tier 4 equivalent standards in subsequent years).

It is recommended consideration be given to regulation of the quality of diesel being used for non-road applications in Australia to ensure efficient and cost-effective emission reductions from the non-road diesel sector. This could be effected either by requiring that diesel meeting the ADO fuel standard be used for non-road applications, or through the development of an additional fuel standard for non-road applications.

Additional Short-term Approach

The establishment of one or more industry-government partnerships (quasi-regulation), focusing on targeted non-road diesel engine/equipment sub-populations would be beneficial in the short-term (in the event that the regulatory development process is lengthy).

The Heavy Industrial (Construction, Mining) Engine/Equipment sub-population represents a feasible target for such an approach given that suppliers of such engines/equipment appear more organised and progressive, and significant reductions in PM_{10} emissions could be achieved through improved emission performance.

Depending on the outcome of preliminary industry consultations, it may be beneficial to limit coverage to larger (above 37 kW) heavy industrial (construction, mining) engines/equipment, thus reducing the number of units being managed without substantially affecting the emission reduction achievable.

The commitment to progressive reduction of emissions can be reflected in a Memorandum of Understanding, with CMEIG to provide aggregated sales figures periodically, including information on the emission performance status of products sold.

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11 Abbreviations

ABS	Australian Bureau of Standards
ADEDA	Australian Diesel Engine Distributors Association
ADO	Automotive Diesel Oil
AQIS	Australian Quarantine and Inspection Service
CARB	California Air Resources Board
CDPFs	catalysed diesel particulate filters (CDPFs)
CEN	European Standards Organization
CMEIG	Construction and Mining Equipment Industry Group
CO	Carbon monoxide
DECCW	NSW Department of Environment Climate Change and Water
DEWHA	Australian Department of Environment, Water, Heritage and the Arts
DF	deterioration factor
DOCs	diesel oxidation catalysts
DPM	diesel particulate matter
ERG	Equipment Research Group Pty Ltd (ERG International)
GMR	Greater Metropolitan Region
ktpa	kilotonnes per annum
NCDC	USEPA's *National Clean Diesel Campaign*
NEPC	National Environment Protection Council
NEPM	National Environmental Protection Measure
NOx	Oxides of nitrogen
NMHC	Non-methane hydrocarbons
NRMM	Non-road Mobile Machinery
NRTC	Non-road Transient Cycle
OEM	Original Equipment Manufacturers
PAH	polycyclic aromatic hydrocarbons

PM	Particulate matter
PM_{10}	Particulate matter with an aerodynamic diameter of less than 10 microns
$PM_{2.5}$	Particulate matter with an aerodynamic diameter of less than 2.5 microns
SCR	selective catalytic reduction
SO_2	sulfur dioxide
TAF	transient adjustment factor
THC	total hydrocarbons
TMA	Tractor and Machinery Association of Australia
tpa	tonnes per annum
TPM	Total Particulate Matter
ULSD	ultra low sulfur diesel
US-EPA	United States Environmental Protection Agency
VOC	volatile organic compound
ZHL	‘zero-hour’ emission level