NSW Coal Mining Benchmarking Study

Best-practice measures for reducing non-road diesel exhaust emissions

Final draft report

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EXECUTIVE SUMMARY

Project Background

This project complements the *NSW coal mining benchmarking study: International best practice measures to prevent and/or minimise emissions of particulate matter from coal mining* (Katestone Environmental, 2011), which is being implemented by the EPA through the *Dust Stop* program (EPA, 2011).

The aim of this project is to complete a cost benefit analysis (CBA), which evaluates a number of options for reducing exhaust particulate matter (PM) emissions from non-road diesel vehicles and equipment (non-road diesels) for all 64 coal mines in NSW that hold a current environment protection licence (EPL) (EPA, 2013a). The main focus of this project is about non-road diesels used in surface applications at both open-cut and underground coal mines but it specifically excludes non-road diesels used in underground applications.

Given that approximately 90% of all diesel consumed by EPA-licensed coal mines is in the high power (≥ 560 kW) equipment class (EPA, 2013b), this project is principally aimed at evaluating options for reducing PM emissions from non-road diesels in this class.

The scope of this project includes:

- Review international best practice measures to reduce non-road diesel emissions at NSW coal mines
- Conduct a survey of all EPA-licensed coal mines to determine the size, composition, emissions certification, activity levels, fuel types and consumption and maintenance practices of the non-road diesel fleet
- Compare international best practice measures to reduce non-road diesel emissions with those currently used at each NSW coal mine
- Make recommendations regarding the adoption of international best practice measures that could be practicably implemented at each NSW coal mine
- Estimate the likely reduction in non-road diesel emissions and health costs associated with adopting each international best practice measure at each NSW coal mine
- Estimate the costs associated with adopting each international best practice measure at each NSW coal mine
- Implement the findings by attaching a pollution reduction program (PRP) to EPL conditions (similar to the process followed for the *Dust Stop* program) in order to prevent and/or minimise non-road diesel exhaust emissions at EPA-licensed coal mines in NSW. The PRP should only apply to non-road diesels used in surface applications at both open-cut and underground coal mines.

This report presents the supporting scientific, technical, health and economic based evidence, in order to objectively establish the extent to which non-road diesel exhaust PM emissions can be practicably reduced.

Health Effects of Particulate Matter

Numerous scientific studies have linked PM exposure to a variety of lung and heart problems, including: premature death in people with heart or lung disease; nonfatal heart attacks; irregular heartbeat; aggravated asthma; decreased lung function; and increased respiratory symptoms (leading to hospital admissions and emergency room visits), such as irritation of the airways, coughing or difficulty breathing (USEPA, 2009a).

People with heart or lung diseases, children and older adults are the most likely to be affected by PM exposure. However, even healthy individuals may experience temporary symptoms from exposure to elevated levels of PM. Both long (over years) and short term (hours or days) PM exposure has been linked to health problems. While there is no safe level of exposure for PM, the risk of health impacts decreases with lower levels of exposure (WHO, 2006).

The International Agency for Research on Cancer (IARC), which is part of the World Health Organization (WHO), has now classified diesel engine exhaust as carcinogenic to humans (Group 1), based on sufficient evidence that exposure is associated with an increased risk for lung cancer (IARC, 2012). The IARC has also identified that air pollution as a whole (including the small particles that make up part of air pollution) causes cancer (IARC, 2013).

Health Costs of Particulate Matter

More Australians die each year from air pollution (3,056) than from road traffic accidents (1,662) (AIHW, 2007). Many more Australians, primarily children, the elderly and those with respiratory conditions, live with impaired health and quality of life due to air pollution. Air pollution causes 27,519 disability-adjusted life years (DALY)) (AIHW, 2007).

Although air quality in NSW is relatively good by international standards and has been steadily improving over time (DECCW, 2010), it still imposes major costs on NSW communities. The health costs of air pollution in the NSW Greater Metropolitan Region (GMR) have been calculated at $4.7 billion per annum (DEC, 2005a). Transport emissions alone have been calculated to have health costs of $2.7 billion per year in Australia (BTRE, 2005). The most significant health costs result from exposure to PM and to a lesser extent, ground-level ozone (O_3).

Ambient Air Quality, Sources of Particulate Matter and Particle Composition

The *National Environment Protection (Ambient Air Quality) Measure* (Ambient Air Quality NEPM) establishes ambient air quality standards for six key pollutants (carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO_2), PM_{10}, O_3, sulfur dioxide (SO_2) and $PM_{2.5}$) and provides jurisdictions with a standard way of monitoring and reporting on ambient air quality (NEPC, 2003).

Current Air Quality in New South Wales (DECCW, 2010) and *New South Wales State of the Environment 2012* (EPA, 2012b) show that ambient levels of CO, Pb, NO_2 and SO_2 are all consistently below their respective Ambient Air Quality NEPM standards in most areas. However, ambient levels of O_3 in urban areas and particulate matter (PM_{10} & $PM_{2.5}$)) in both rural and urban areas can exceed Ambient Air Quality NEPM standards, so they are the pollutants of greatest concern in those regions (DECCW, 2010 & EPA, 2012b).

In terms of primary $PM_{2.5}$ emissions, commercial and industrial (EPA-licensed) non-road vehicles and equipment (diesel, gas and petrol) contribute 5% (natural & anthropogenic)/6% (anthropogenic) in the GMR and 11% (natural & anthropogenic)/12% (anthropogenic) in the Hunter region. Commercial and industrial (EPA-licensed) non-road vehicles and equipment (diesel, gas and petrol) are the sixth and third largest source of primary $PM_{2.5}$ emissions in the GMR and Hunter region, respectively. In the GMR, emissions of primary $PM_{2.5}$ from diesel non-road vehicles and equipment (non-road diesels) at coal mines have been estimated to be 86% of all commercial and industrial (EPA-licensed) non-road vehicles and equipment (diesel, gas and petrol) emissions in the GMR. Similarly, in the Hunter region, emissions of primary $PM_{2.5}$ from non-road diesels at coal mines have been estimated to be 95% of all commercial and industrial (EPA-licensed) non-road vehicles and equipment (diesel, gas and petrol) emissions in the Hunter region. Non-road diesels at coal mines are a significant source of primary $PM_{2.5}$ emissions in the GMR and the Hunter region (EPA, 2012a).

The *Upper Hunter Fine Particle Characterisation Study* (Hibberd et. al., 2013) found that vehicles/industry make a significant contribution to the make-up of ambient $PM_{2.5}$ at the Singleton (17%) and Muswellbrook (8%) monitoring sites.

When interpreting source pollution and particle composition data, it is important to understand the relationship between PM emissions and ambient concentrations is quite complex and influenced by a number of factors. How these emissions are dispersed, transported and transformed depends primarily on meteorology, topography, atmospheric reactions and source type. While air emissions inventory data provides information on the key emission sources in a geographical area, it cannot be directly used to estimate ambient concentrations. Particle composition data provides the best estimate of the PM sources which influence ambient concentrations in those locations where ambient monitoring has been carried out.

Air Pollution Legislation in NSW

The *Fuel Quality Standards Act 2000* (Attorney-General's Department, 2010) provides the legislative framework for setting national fuel quality and fuel quality information standards for Australia. Fuel quality and fuel quality information standards have been made under the *Fuel Quality Standards Act 2000* for Diesel (*Fuel Standard (Automotive Diesel) Determination 2001* (Attorney-General's Department, 2009a)) and Biodiesel (*Fuel Standard (Biodiesel) Determination 2003* (Attorney-General's Department, 2009b)).

The *Protection of the Environment Operations Act 1997* (POEO Act) (PCO, 2010) provides the statutory framework for managing air emissions in NSW. Reducing risks to human health through pollution prevention, cleaner production, reduction of pollution to harmless levels, application of the waste management hierarchy (i.e. reduction, re-use, recovery and recycling), continual environmental improvement and environmental monitoring are the broad objectives of the POEO Act (Chapter 1, Section 3). Air pollution related Sections 124 to 126 of the POEO Act require that operation of plant, maintenance work on plant and dealing with materials is done in a proper and efficient manner. Section 128 of the POEO Act requires that activities are carried out using those practicable means that may be required to prevent or minimise air pollution. Best management practice (BMP) is clearly the guiding principle in meeting the Objects and Air pollution requirements of the POEO Act.

While the EPA has powers to include EPL conditions aimed at preventing or minimising air pollution emissions from non-road diesels at coal mines, EPLs presently include generic requirements (EPA, 2013a), which are essentially a reiteration of Part 5.4 (Air pollution), Division 1 General of the POEO Act. While BMP is the guiding principle of these operating conditions, the EPLs haven’t traditionally included prescriptive requirements. However, the approach has now evolved through the *Dust Stop* program (EPA, 2011).

The *Dust Stop* program aims to ensure that the most reasonable and feasible PM control options are implemented by each coal mine. The *Dust Stop* program is being implemented through pollution reduction programs (PRP) attached to each coal mine EPL, which aim to reduce emissions of wheel generated dust and dust from handling overburden. The PRP typically include: Key performance indicator; Monitoring method; Location, frequency and duration of monitoring; Record keeping; and Compliance reporting. The *Dust Stop* program provides a sound model for reducing non-road diesel exhaust emissions at EPA-licensed coal mines in NSW.

Since occupational exposure to non-road diesel exhaust emissions at underground coal mines is regulated by the Division of Resources and Energy (DRE) under the *Coal Mine Health and Safety Act 2002* (CMHS Act) (PCO, 2013b), non-road diesels used in underground applications are not within the scope of this project. At EPA-licensed coal mines, over 99% of diesel is consumed by non-road diesels in surface applications, while less than 1% is consumed in underground applications (EPA, 2013b). Since the majority of diesel is consumed in surface applications, a program aimed at reducing non-road diesel exhaust emissions from these equipment will achieve the greatest health benefit to communities situated near coal mines.

Non-Road Diesel Engine Emission Standards and Control Technology

Regulated emission limits for non-road diesels have been in force in the United States (US) (USEPA, 2013a) and European Union (EU) (European Commission, 2013) since the mid-to-late 1990s, and were more recently introduced in Canada, Russia, Switzerland, Turkey, Japan, China, India, South Korea, Singapore and Brazil (Ecopoint Inc., 2013a). With the exception of non-road diesels used in underground coal mine applications, there are no regulations which specifically apply to emissions from non-road diesels in Australia or NSW. A study to gather information and scope possible actions for non-road diesels in Australia found that significant health benefits ranging from \$2.5 to \$4.7 billion by 2030 could potentially be achieved by reducing PM_{10} and NO_x emissions (Environ, 2010).

Retrofit exhaust emission control equipment are a mature technology and able to achieve between 25% (diesel oxidation catalysts (DOC)) (DieselNet, 2012 & Joshi et. al., 2011) and 90% (diesel particulate filters (DPF)) (Lanni et. al., 2001; Chatterjee et. al., 2001; Joshi et. al., 2011 & DieselNet, 2011b) reduction in PM, depending on the technology selected.

Survey of EPA-licensed Coal Mines

A survey of EPA-licensed coal mines (EPA, 2013b) was carried out to provide the detailed supporting technical data required to complete a CBA and objectively establish whether there are technically and economically feasible options available to reduce non-road diesel emissions.

The NSW Minerals Council coordinated industry consultation with BHP Billiton, Peabody, Rio Tinto and Xstrata on the draft EPA survey during February and March 2013. The draft EPA survey was modified in line with comments received during industry consultation.

The EPA survey was issued to 64 EPA-licensed coal mines on 11 April 2013 under the Protection of the Environment Operations Act 1997 (POEO Act) (PCO, 2010) using a Section 191 Notice to Provide Information and/or Records and ended on 24 May 2013.

A 100% response rate to the survey was achieved with high quality data completed and submitted by the 58 operating EPA-licensed coal mines in NSW. The EPA granted six exemptions from participating in the survey, considering these coal mines have little or no non-road diesels activity because they are either closed with rehabilitation complete or in care and maintenance with no foreseeable plans to commence production.

Cost Benefit Analysis

A CBA has evaluated a number of options for reducing exhaust PM emissions from non-road diesels at NSW coal mines over the period from 2012 to 2030, including:

- retrofitting in-service equipment with PM exhaust aftertreatment technologies
- procuring replacement equipment that is compliant with EU (European Commission, 2013) and/or US (USEPA, 2013a) emission standards, and/or
- adopting ultra-low sulfur diesel (10 ppm sulfur) (Attorney-General's Department, 2009a), for all 64 coal mines in NSW that hold a current environment protection licence (EPL) (EPA, 2013a).

Over 99% of diesel consumed by EPA-licensed coal mines has a sulfur content of ≤ 10 ppm and complies with the *Fuel Standard (Automotive Diesel) Determination 2001* (Attorney-General's Department, 2009a), while less than 1% of diesel consumed (predominantly in underground applications) has a sulfur content of 50 – 500 ppm (EPA, 2013b). Given the high uptake of ultra-low sulfur diesel, there is no technical impediment to retrofit in-service non-road diesels with advanced exhaust emission control equipment (DPF) and/or replace with new equipment that has US Tier 4 emissions certification at NSW coal mines. Australian ultra-low sulfur diesel is technically compatible with advanced exhaust aftertreatment and US Tier 4 technologies, so there are no fuel quality related barriers associated with adopting these low diesel emission control technologies at NSW coal mines.

The CBA concludes that:

- all retrofit exhaust emission aftertreatment equipment options have net benefits ranging from 66 to 220 million (2012 AUD)
- replacing equipment with either US Tier 1 or Tier 4 emission standard compliant equipment have net benefits of 46 and 273 million (2012 AUD), respectively
- when replacing equipment with US Tier 4 emission standard compliant equipment, the operating costs savings due to improved fuel efficiency outweigh the capital costs and maintenance costs
- replacing equipment with US Tier 4 emission standard compliant equipment has a net benefit, regardless of whether the health benefits are considered
- combining in-service retrofit with passive DPF and replacing equipment with US Tier 4 emission standard compliant equipment has the highest net benefit of 345 million (2012 AUD)
- replacing equipment with either US Tier 2 or Tier 3 emission standard compliant equipment have negative net benefits due to lower fuel efficiency.

It should be noted the net benefits when replacing equipment with US Tier 4 emission standard compliant equipment do not include Adblue coal mine site infrastructure cost, which has been estimated to be $3.0 million (2012 AUD) (refer to Section 5.5.3 for further details).

A number of factors could lead to either an under or over estimation of the net benefits presented in the CBA, including:

- **Forecast coal mine production** – the CBA forecasts emission reductions and net monetary benefits for existing EPA-licensed coal mines only. Since only the forecast saleable coal production for the 58 EPA-licensed coal mines that completed the survey has been considered (EPA, 2013b), future diesel consumption could have been underestimated by at least 40%, leading to increased $PM_{2.5}$ emissions and health costs
- **Assign a Significant Urban Area (SUA) to coal mine suburb/town** - the CBA assigns each coal mine suburb/town to the nearest Significant Urban Area (SUA) using a concordance table of Statistical Area 2 (SA2) to SUA. While the unit damage costs have been discretely calculated on a SUA basis, the airsheds approximated by each SUA are in reality part of a contiguous airshed with the surrounding areas. It should also be noted that $PM_{2.5}$ have atmospheric lifetimes of days to weeks and can travel from 100s to 1,000s of km. Since many of the Upper Hunter coal mines that are located outside of a SUA are within 10 km or less of the SUA boundary, the $PM_{2.5}$ emissions from those premises will still make a significant contribution to the ambient levels of $PM_{2.5}$ in that SUA. A sensitivity analysis has been done by assigning coal mines to the nearest SUA using a concordance table of suburb to SUA. The sensitivity analysis concludes that all retrofit, replacement and combined retrofit and replacement options with the exception of two have net benefits for any SUA assignment method. Replacement with either US Tier 2 or Tier 3 emission standards compliant equipment have negative net benefits for any SUA assignment method
- **Health benefits beyond 2030** - the CBA forecasts emission reductions and net monetary benefits over the period from 2012 to 2030 only. Although additional emission reductions and net monetary benefits could potentially accrue by accounting for measures to reduce emissions from non-road diesels beyond 2030, they have not been quantified in the CBA but are likely to be substantial
- **Health impacts of NO_x emissions** - the CBA forecasts emission reductions and net monetary benefits for primary $PM_{2.5}$ only. While retrofit options do not reduce NO_x emissions, replacement of equipment with ones that meet more stringent US non-road diesel regulations can achieve

significant NO_x reductions. The NSW Environment Protection Authority (EPA) *Reducing Emissions from Non-Road Diesel Engines Information Report* (EPA Information Report) estimates the NO_x unit damage costs to be about 2% (includes NO_2 and secondary PM) of $PM_{2.5}$ unit damage costs (EPA, 2014). While NO_x can contribute to human health impacts in three distinct ways, the CBA has not quantified the health costs and benefits associated with NO_2, O_3 and secondary PM

- **Workplace exposure** – the CBA quantifies health costs and benefits for the broader community only. Although emission reduction measures will also reduce occupational exposure to diesel exhaust, they have not been quantified in the CBA but are likely to be significant (AIOH, 2013)
- **Fuel efficiency** – the CBA accounts for changes in fuel efficiency for both retrofit and replacement options. With the exception of active DPF, retrofit options do not significantly affect fuel efficiency. While replacement with either US Tier 2 or Tier 3 options have negative net benefits, replacement with US Tier 4 has a net benefit regardless of whether the health benefits are considered due to improved fuel efficiency. If the US Tier 4 fuel efficiency is varied within a reasonable range, the net benefits of the option range from break even to 599 million (2012 AUD)
- **Adblue consumption rate** - the CBA assumes a fleet average Adblue consumption of 1.4% expressed as a percentage of diesel consumption for US Tier 4 non-road diesels. Not all OEMs have made final announcements on the US Tier 4 NO_x control technology (either SCR or EGR) that will be used and the average percentage Adblue consumption may vary between manufacturers. A sensitivity analysis has been conducted for a fleet average Adblue consumption of 3.5% diesel consumption. The sensitivity analysis concludes that all replacement and combined retrofit and replacement options that include US Tier 4 demonstrate a significant net benefit when using the higher Adblue consumption rate
- **Adblue storage tank and dispenser equipment** – the CBA does not include the cost of Adblue storage tank and dispenser equipment at coal mine sites. The total cost to equip all NSW open-cut coal mines with Adblue storage tanks and dispensers in order to cater for a fleet made up of entirely US Tier 4 non-road diesels has been estimated to be $3.0 million (2012 AUD), which is about 1% of the net benefit. All replacement and combined retrofit and replacement options that include US Tier 4 demonstrate a significant net benefit when including Adblue storage tank and dispenser equipment costs
- **Exhaust aftertreatment retrofit capital, operating and maintenance costs** – the CBA uses cost data from exhaust aftertreatment equipment retrofit suppliers and OEMs. A sensitivity analysis has been done using alternative capital, operating and maintenance costs for the retrofit of DOC and DPF exhaust aftertreatment equipment. The sensitivity concludes that all retrofit and combined retrofit and replacement options demonstrate a net benefit with the higher costs
- **Exhaust aftertreatment weight and space constraints** – the CBA does not include the impact of DPF retrofit on payload and any associated loss in productivity. It is acknowledged that certain equipment may have engineering limitations and these may not be suitable for DPF retrofit. Weight and space constraints associated with retrofitting exhaust aftertreatment equipment should be addressed for each piece of mining equipment used by EPA-licensed coal mines in the PRP process. Since DOC are significantly smaller and lighter than DPF and can generally be accommodated within existing exhaust systems and mufflers, DOC retrofit is unlikely to impact on payload and have any associated loss in productivity
- **Discount rate** - the CBA assumes a discount rate of 7%, which is based on NSW Treasury economic appraisal guidance (NSW Treasury, 2007a, 2007b & 2007c). A sensitivity analysis has been done assuming discount rates of 4% and 10% (NSW Treasury, 2007b). The sensitivity analysis concludes that all retrofit, replacement and combined retrofit and replacement options with the exception of two have net benefits for discount rates ranging from 4% to 10%. Replacement with either US Tier 2 or Tier 3 emission standards compliant equipment have negative net benefits for any discount rate
- **Voluntary equipment replacement strategy** - the CBA assumes the voluntary equipment replacement strategy for the BAU or ‘do nothing’ option is to purchase equipment with the existing

level of emissions certification. As a worst case in order to maximise costs (especially fuel consumption) and minimise benefits (reduction in $PM_{2.5}$ emissions), a sensitivity analysis has been done by assuming the existing fleet performance is either US Tier 1 or Tier 2. In other words, the voluntary equipment replacement strategy for the BAU option is to purchase equipment with either US Tier 1 or Tier 2 level of emissions certification. Assuming the existing fleet performance is either US Tier 1 or Tier 2 provides a suitable basis for evaluating the likely range of net benefits associated with a mandated US Tier 4 replacement strategy. This approach results in a voluntary equipment replacement strategy that has between 75% (US Tier 1) and 50% (US Tier 2) of the $PM_{2.5}$ emissions when compared to BAU. The sensitivity analysis concludes that:

  - if the existing fleet performance is US Tier 2, all retrofit, replacement and combined retrofit and replacement options have net benefits, with the exception of retrofit with active DPF, which has a negative net benefit of -6 million (2012 AUD)
  - if the existing fleet performance is US Tier 1, all retrofit, replacement and combined retrofit and replacement options have net benefits
  - as the natural turnover of the existing fleet tends to either US Tier 2 and/or Tier 3 emission standards compliant equipment, the net benefits associated with a mandated US Tier 4 replacement strategy increase due to improved fuel efficiency.

- **Administration and compliance costs** - the CBA does not include administration and compliance costs. The EPA Information Report (EPA, 2014) presents the costs and benefits associated with introducing US Tier 4 emission standards. Administration and compliance costs have been estimated to account for about 1% of total costs over the 19 year period considered in this CBA and have little effect on the net benefit.

Overall, it is our view the CBA under estimates the net benefits of reducing non-road diesel exhaust emissions and this is largely influenced by future coal mine production, health benefits beyond 2030 and workplace exposure.

Recommendations

This report objectively confirms there are both technically and economically feasible options for reducing non-road diesel exhaust PM emissions. The findings in this report should form the basis for developing PRP in the short term, which are aimed at reducing non-road diesel exhaust emissions at EPA-licensed coal mines in NSW.

For in-service non-road diesel retrofit, an appropriate performance benchmark is at least 25% reduction in PM emissions, which requires the use of either diesel oxidation catalyst (DOC), passive or active diesel particulate filter (passive or active DPF) exhaust emissions aftertreatment equipment, where practicable. To ensure the largest emission reductions and health benefits are achieved, retrofits should be timed to commence with the first scheduled engine rebuild on or after 1 January 2015.

For new replacement non-road diesels, an appropriate performance benchmark is US Tier 4 or equivalent, where practicable. To ensure the largest emission reductions and health benefits are achieved, replacements should be timed to commence with the first scheduled equipment replacement on or after 1 January 2018.

These implementation dates are based on the assumptions used in the CBA. Through the PRP process, reasonable implementation timeframes should be negotiated with EPA-licensed coal mines to account for site specific issues.

It is recommended that all existing and proposed NSW coal mines should conduct a best management practice (BMP) determination to identify the most technically and economically feasible options for reducing non-road diesel exhaust emissions for both existing in-service and new replacement equipment.

Similar to the *Dust Stop* program, this approach has the primary aim of ensuring the most reasonable and feasible PM emissions control options are implemented by each coal mine. All existing EPA-licensed coal mines should be provided with a reasonable timeframe to prepare a report that compares their current operation with international best practice. EPA-licensed coal mines should also be required to report on the practicability of implementing each best practice measure. For any measures found to be practicable, each EPA-licensed coal mine should be required to provide a timetable for implementation. The PRP should only apply to non-road diesels used in surface applications at both open-cut and underground coal mines.

The BMP determination should:
(1) be implemented through a pollution reduction program (PRP), which is enforced through environment protection licence (EPL) conditions
(2) form part of the Environmental Assessment (EA) for proposed coal mine developments, which is directly linked to the air quality impact assessment.

Pollution reduction programs provide a transparent, efficient, equitable, auditable and enforceable manner in which the EPA can exercise its powers under the POEO Act in order to reduce regional and local PM levels by taking into account site specific issues at each EPA-licensed coal mine.

EPA-licensed coal mines are required to submit an annual return form to the EPA. The annual return is a statement of compliance with environment protection licence (EPL) conditions for the preceding 12 months. The non-road diesel performance standards, operation and maintenance requirements for in-service retrofit and new replacement equipment should be included as EPL conditions and compliance determined using the existing annual return process.

The EPA should provide further opportunity for stakeholder comments on the proposed PRP when this report is published.

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ABBREVIATIONS

ABS	Australian Bureau of Statistics
ADR	Australian Design Rules
ANZSIC	Australia New Zealand Standard Industry Classification
BSFC	Brake specific fuel consumption
C-RIS	Consultation Regulation Impact Statement
CBA	Cost benefit analysis
CO	Carbon monoxide
Commercial	Not a scheduled activity or scheduled development work as defined in the POEO Act
DEFRA	UK Department of Environment, Food and Rural Affairs
DOC	Diesel oxidation catalyst
DPF	Diesel particulate filter
DSEWPC	Australian Government Department of Sustainability, Environment, Water, Population and Communities
EGR	Exhaust gas recirculation
EPA	NSW Environment Protection Authority
EPL	Environment Protection License issued under the POEO Act
EU	European Union
GMR	NSW Greater metropolitan region; includes urban areas of Sydney, Newcastle and Wollongong
HP	Horsepower
Hunter region	Area including the local government areas of Cessnock, Dungog, Great Lakes, Lake Macquarie, Maitland, Muswellbrook, Newcastle, Port Stephens, Singleton & Upper Hunter Shire
Industrial	An activity listed in Schedule 1 of the POEO Act
IARC	International Agency for Research on Cancer
kL	kilolitres (1,000 litres)
kW	kilowatt (1,000 watts)
LGA	Local government area
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NH_3	Ammonia
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_x	Oxides of nitrogen, including NO and NO_2
NPI	National Environment Protection (National Pollutant Inventory) Measure
O_3	Ozone
pDPF	Partial diesel particulate filter
Pb	Lead
PM	Particulate matter
PM_{10}	PM with aerodynamic equivalent diameter of less than 10 micrometres
$PM_{2.5}$	PM with aerodynamic equivalent diameter of less than 2.5 micrometres
POEO Act	Protection of the Environment (Operations) Act 1997
Clean Air Regulation	Protection of the Environment Operations (Clean Air Regulation) 2010
ROM coal	Run-of-mine coal
SCR	Selective catalytic reduction
SO_2	Sulfur dioxide

SUA	Significant urban area defined by ABS
TSP	Total suspended particles – PM with aerodynamic equivalent diameter less than approximately 30 micrometres
UFP	Ultra-fine particles – PM with aerodynamic equivalent diameter less than approximately 0.1 micrometres
UHAQMN	Upper Hunter Air Quality Monitoring Network
$\mu g/m^3$	microgram per cubic meter
μm	micron or micrometre, one millionth of a meter or 1/1000 of a millimetre
USEPA	United States Environment Protection Agency
VOC	Volatile organic compounds
WHO	World Health Organisation

1 INTRODUCTION

This section describes the project background, its aim and objective, the scope of the project and associated analysis and provides a summary overview of the report.

1.1 Project Background

People with heart or lung diseases, children and older adults are the most likely to be affected by PM exposure. However, even healthy individuals may experience temporary symptoms from exposure to elevated levels of PM. Both long (over years) and short term (hours or days) PM exposure has been linked to health problems. While there is no safe level of exposure for PM, the risk of health impacts decreases with lower levels of exposure (WHO, 2006).

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The *National Environment Protection (Ambient Air Quality) Measure* (Ambient Air Quality NEPM) establishes ambient air quality standards for six key pollutants (carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO_2), PM_{10}, O_3, sulfur dioxide (SO_2) and $PM_{2.5}$) and provides jurisdictions with a standard way of monitoring and reporting on ambient air quality (NEPC, 2003).

Current Air Quality in New South Wales (DECCW, 2010) and *New South Wales State of the Environment 2012* (EPA, 2012b) show that ambient levels of CO, Pb, NO_2 and SO_2 are all consistently below their respective Ambient Air Quality NEPM standards in most areas. However, ambient levels of O_3 in urban areas and particulate matter (PM_{10} & $PM_{2.5}$)) in both rural and urban areas can exceed Ambient Air Quality NEPM standards, so they are the pollutants of greatest concern in those regions (DECCW, 2010 & EPA, 2012b).

In terms of primary $PM_{2.5}$ emissions, commercial and industrial (EPA-licensed) non-road vehicles and equipment (diesel, gas and petrol) contribute 5% (natural & anthropogenic)/6% (anthropogenic) in the GMR and 11% (natural & anthropogenic)/12% (anthropogenic) in the Hunter region. Commercial and industrial (EPA-licensed) non-road vehicles and equipment (diesel, gas and petrol) are the sixth and third largest source of primary $PM_{2.5}$ emissions in the GMR and Hunter region, respectively. In the GMR, emissions of primary $PM_{2.5}$ from diesel non-road vehicles and equipment (non-road diesels) at coal mines have been estimated to be 86% of all commercial and industrial (EPA-licensed) non-road vehicles and equipment (diesel, gas and petrol) emissions in the GMR. Similarly, in the Hunter region, emissions of primary $PM_{2.5}$ from non-road diesels at coal mines have been estimated to be 95% of all commercial and industrial (EPA-licensed) non-road vehicles and equipment (diesel, gas and petrol) emissions in the Hunter region. Non-road diesels at coal mines are a significant source of primary $PM_{2.5}$ emissions in the GMR and the Hunter region (EPA, 2012a).

The *Upper Hunter Fine Particle Characterisation Study* (Hibberd et. al., 2013) found that vehicles/industry make a significant contribution to the make-up of ambient $PM_{2.5}$ at the Singleton (17%) and Muswellbrook (8%) monitoring sites.

Regulated emission limits for non-road diesels have been in force in the United States (US) (USEPA, 2013a) and European Union (EU) (European Commission, 2013) since the mid-to-late 1990s, and were more recently introduced in Canada, Russia, Switzerland, Turkey, Japan, China, India, South Korea, Singapore and Brazil (Ecopoint Inc., 2013a). With the exception of non-road diesels used in underground coal mine applications, there are no regulations which specifically apply to emissions from non-road diesels in Australia or NSW. A study to gather information and scope possible actions for non-road diesels in Australia found that significant health benefits ranging from $2.5 to $4.7 billion by 2030 could potentially be achieved by reducing PM_{10} and NO_x emissions (Environ, 2010).

Retrofit exhaust emission control equipment are a mature technology and are able to achieve between 25% (diesel oxidation catalysts (DOC)) (DieselNet, 2012 & Joshi et. al., 2011) and 90% (diesel particulate filters (DPF) (Lanni et. al., 2001; Chatterjee et. al., 2001; Joshi et. al., 2011 & DieselNet, 2011b) reduction in PM, depending on the technology selected.

Since non-road diesels are a significant source of PM emissions in NSW, a substantial health benefit could potentially be achieved by reducing these emissions using proven technologies. This report presents a cost benefit analysis (CBA) for reducing exhaust PM emissions from non-road diesels at NSW coal mines.

1.2 Project Aim and Objective

This project complements the *NSW coal mining benchmarking study: International best practice measures to prevent and/or minimise emissions of particulate matter from coal mining* (Katestone Environmental, 2011), which is being implemented by the EPA through the *Dust Stop* program (EPA, 2011).

The main focus of this project is about non-road diesels used at open-cut rather than underground coal mines (except for surface equipment). Since non-road diesels at underground coal mines are regulated by the Division of Resources and Energy (DRE) under the *Coal Mine Health and Safety Act 2002* (CMHS Act) (PCO, 2013b) (refer to Section 4.3 for further details), reducing emissions from non-road diesels used in underground applications are not within the scope of this project. The estimated fuel consumption and PM emissions and the CBA findings presented in this report only relate to non-road diesels used at open-cut rather than underground coal mines (except for surface equipment).

The aim of this project is to complete a CBA, which evaluates a number of options for reducing exhaust PM emissions from non-road diesel vehicles and equipment (non-road diesels), including:

- retrofitting in-service equipment with PM exhaust aftertreatment technologies
- procuring replacement equipment that is compliant with EU (European Commission, 2013) and/or US (USEPA, 2013a) emission standards, and/or
- adopting ultra-low sulfur diesel (10 ppm sulfur) (Attorney-General's Department, 2009a), for all 64 coal mines in NSW that hold a current environment protection licence (EPL) (EPA, 2013a).

Given that approximately 90% of all diesel consumed by EPA-licensed coal mines is in the high power (≥ 560 kW) equipment class (EPA, 2013b), this project is principally aimed at evaluating options for reducing PM emissions from non-road diesels in this class.

The objective of this project is to implement the findings in the short term, by attaching a pollution reduction program (PRP) to EPL conditions (similar to the process followed for the *Dust Stop* program) in order to prevent and/or minimise non-road diesel exhaust emissions at EPA-licensed coal mines in NSW. The PRP should only apply to non-road diesels used in surface applications at both open-cut and underground coal mines.

In the medium term, emission standards and implementation timeframes for in-service and new replacement equipment could also be introduced in the *Protection of the Environment Operations (Clean Air) Regulation 2010* (POEO Clean Air Regulation) (PCO, 2011a), although this is a separate piece of work.

1.3 Project Scope and Report Overview

The scope of this project includes:

- Review international best practice measures to reduce non-road diesel emissions at NSW coal mines
- Conduct a survey of all EPA-licensed coal mines to determine the size, composition, emissions certification, activity levels, fuel types and consumption and maintenance practices of the non-road diesel fleet
- Compare international best practice measures to reduce non-road diesel emissions with those currently used at each NSW coal mine
- Make recommendations regarding the adoption of international best practice measures that could be practicably implemented at each NSW coal mine
- Estimate the likely reduction in non-road diesel emissions and health costs associated with adopting each international best practice measure at each NSW coal mine
- Estimate the costs associated with adopting each international best practice measure at each NSW coal mine
- Implement the findings by attaching a pollution reduction program (PRP) to EPL conditions (similar to the process followed for the *Dust Stop* program) in order to prevent and/or minimise non-road diesel exhaust emissions at EPA-licensed coal mines in NSW. The PRP should only apply to non-road diesels used in surface applications at both open-cut and underground coal mines.

It is critical to determine the most cost and environmentally effective ways to reduce air pollution and achieve better air quality for the community. This report presents the supporting scientific, technical, health and economic based evidence, in order to objectively establish the extent to which non-road diesel exhaust PM emissions can be practicably reduced. The report includes the background, methodology, data, analysis and findings of the study as follows:

Section 2 – Definitions, Environmental Impacts, Health Effects and Health Costs of Particulate Matter - provides some key definitions of PM, a summary of the environmental impacts and health effects of PM, ambient air quality standards and criteria for PM (which apply across Australia and NSW), the health costs of air pollution across Australia and NSW and a method for valuing the health costs of PM across NSW communities.

Section 3 – Ambient Air Quality and Particulate Matter Pollution Sources in NSW - lists the air pollutants of greatest concern in NSW, a summary of ambient air quality across NSW and around communities located near coal mines, sources of primary PM pollution derived from air emissions inventories and the composition of PM in ambient air at communities situated close to coal mines.

Section 4 – Air Pollution Legislation in NSW - summarises the air pollution legislation, which applies in NSW to air pollution in general and coal mines, fuels and non-road diesels in particular.

Section 5 – Worldwide Non-Road Diesel Engine Emission Standards and Costs - provides an overview of new worldwide emission standards and capital, maintenance and operating costs for non-road diesels.

Section 6 – In-Service Non-Road Diesel Engine Emission Control Technologies and Costs - provides a summary of in-service exhaust aftertreatment technologies and capital, maintenance and operating costs for non-road diesels. Companies that develop and manufacture or supply and install retrofit exhaust aftertreatment equipment for non-road diesels are also listed and discussed.

Section 7 - Non-Road Diesel Engine Emission Survey of NSW Coal Mines - describes the survey of EPA-licensed coal mines and provides a detailed summary of the survey findings.

Section 8 – Estimated Costs and Benefits of Reducing Non-Road Diesel Engine Particulate Matter at NSW Coal Mines - describes the non-road diesel fuel consumption and emissions estimation model developed for this project. The CBA methodology is also described, including unit damage costs for PM, along with equipment, maintenance and operating costs for new replacement non-road diesels and retrofit exhaust aftertreatment equipment for in-service non-road diesels. A number of retrofit, replacement and combined retrofit and replacement options for reducing non-road diesel exhaust emissions are presented in detail and a summary of the CBA is included. Unquantified benefits are discussed and a sensitivity analysis for key assumptions is presented.

Section 9 – Summary and Recommendations – provides a summary and recommendations.

Section 10 - References - provides a complete list of references.

2 DEFINITIONS, ENVIRONMENTAL IMPACTS, HEALTH EFFECTS AND HEALTH COSTS OF PARTICULATE MATTER

This section provides some key definitions of particulate matter (PM), a summary of the environmental impacts and health effects of PM, ambient air quality standards and criteria for PM (which apply across Australia and NSW), the health costs of air pollution across Australia and NSW and a method for valuing the health costs of PM across NSW communities.

2.1 Definitions of Particulate Matter

This section outlines some key characteristics of PM and discusses the composition of diesel exhaust emissions.

2.1.1 Particulate matter characteristics

Particulate matter refers to a complex mixture of substances suspended in ambient air, including solid particles, liquid droplets and aggregates of particles and liquids. Particulate matter is made up of a number of components, including soot, soil, dust particles, metallic compounds, nitrates and sulfates and organic compounds. While primary PM is directly emitted, secondary PM is formed when precursor gases undergo atmospheric chemical reactions (USEPA, 2009a).

Particles in ambient air range in diameter from approximately 0.001 micrometres (µm) to about 30 µm. Figure 2-1 shows the size range of typical particles and gas dispersoids (Lapple, 1961).

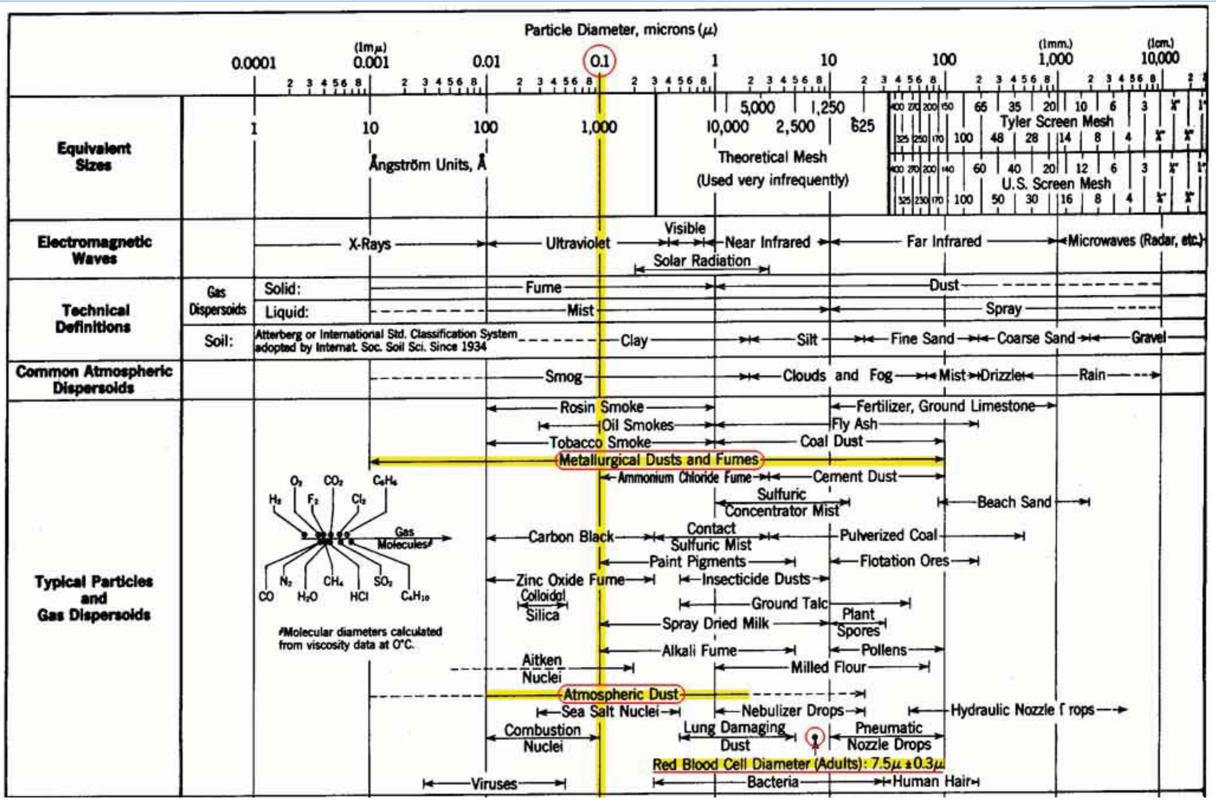


Figure 2-1: Characteristics of typical particles and gas dispersoids

Particulate matter is classified by size as Total Suspended Particulate (TSP), PM_{10} and $PM_{2.5}$. Total Suspended Particulate includes particles with a maximum size of approximately 30 µm and includes

PM_{10} and $PM_{2.5}$. PM_{10} refers to all particles with an aerodynamic equivalent diameter less than 10 µm and includes $PM_{2.5}$. $PM_{2.5}$ refers to all particles with an aerodynamic equivalent diameter less than 2.5 µm.

Typically, larger particles (~30 µm) are deposited within minutes to hours while smaller particles (~2.5 µm) can stay suspended in ambient air for days or weeks (USEPA, 2009a).

Table 2-1 provides a description of TSP, PM_{10} and $PM_{2.5}$, including typical atmospheric lifetimes and distances travelled in the atmosphere (USEPA, 2009a).

Table 2-1: Characteristics of particulate matter

Particle size	Description	Atmospheric lifetime	Distance travelled
TSP	Total Suspended Particulate (TSP) refers to all particles smaller than 30 µm in diameter and is mainly produced from mechanical processes	Minutes to hours	Less than 1 and up to 10s of km. Tendency to fallout in the immediate area downwind of the source
PM_{10}	A subset of TSP and refers to all particles smaller than 10 µm in diameter. $PM_{2.5-10}$ refers to particles in the size range 2.5 µm to 10 µm, which are also known as *coarse particles* and is mainly produced from mechanical processes	Days	Up to 100s of km
$PM_{2.5}$	A subset of TSP and PM_{10} and refers to all particles less than 2.5 µm in diameter. $PM_{2.5}$ is also known as *fine particles* and is mainly produced from a combination from mechanical and combustion processes	Days to weeks	100s to 1000s of km

Particles occur in a wide range of shapes and sizes and are rarely spherical. The size is classified in terms of how a particle behaves in ambient air relative to a spherical particle with a density of 1,000 kg/m^3 and this is termed the aerodynamic equivalent diameter. Particles with diameters of 2.5 µm and 10 µm are compared with human hair and fine beach sand in Figure 2-2 (USEPA, 2013b).

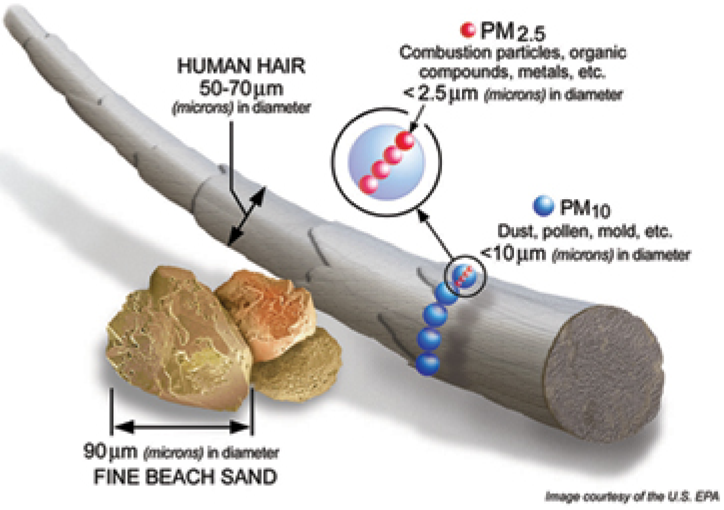


Figure 2-2: PM_{10} and $PM_{2.5}$ compared with human hair and fine beach sand

Filterable and condensable PM emissions are responsible for primary PM pollution. Oxides of nitrogen (NO_x), volatile organic compounds (VOC), sulfur dioxide (SO_2) and ammonia (NH_3) react in the atmosphere to form secondary organic aerosols, and inorganic nitrate and sulfate compounds, which are collectively known as secondary PM pollution. Fine PM pollution is made up of both directly emitted primary emissions and secondary organic and inorganic aerosols (formed through atmospheric reactions). Typical primary and secondary particles are shown in Figure 2-3.

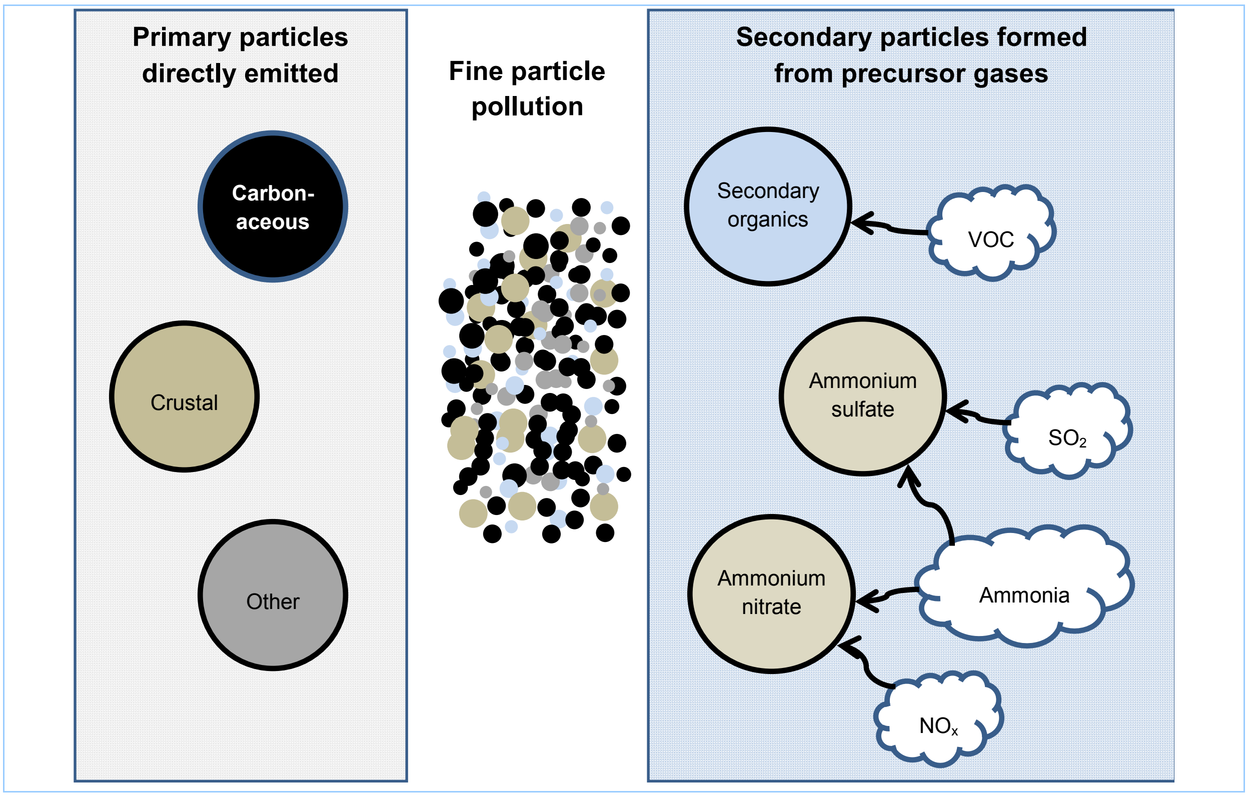


Figure 2-3: Typical primary and secondary particles

2.1.2 Diesel exhaust emissions composition

Diesel exhaust is composed of:

- **gas phase** - which typically includes NO_x, carbon monoxide (CO), carbon dioxide (CO_2), organic compounds such as alkanes, alkenes, aromatic and oxygenated organic compounds including ‘air toxics’ such as acetaldehyde, acrolein, benzene, 1,3-butadiene, formaldehyde and polycyclic aromatic hydrocarbons (PAH)
- **particle phase** - which typically includes a:
  - **solid or insoluble/non-volatile fraction**, including elemental carbon (soot) with small amounts of inorganic ash (metals and other trace elements), and
  - **soluble or volatile fraction**, including organic compounds (hydrocarbons and oxygenated hydrocarbons), sulfate and nitrate adsorbed onto the solid particles, where both phases contribute to human health impacts.

A conceptual model of diesel particulate matter (DPM) composition is shown in Figure 2-4 (Eastwood, 2008).

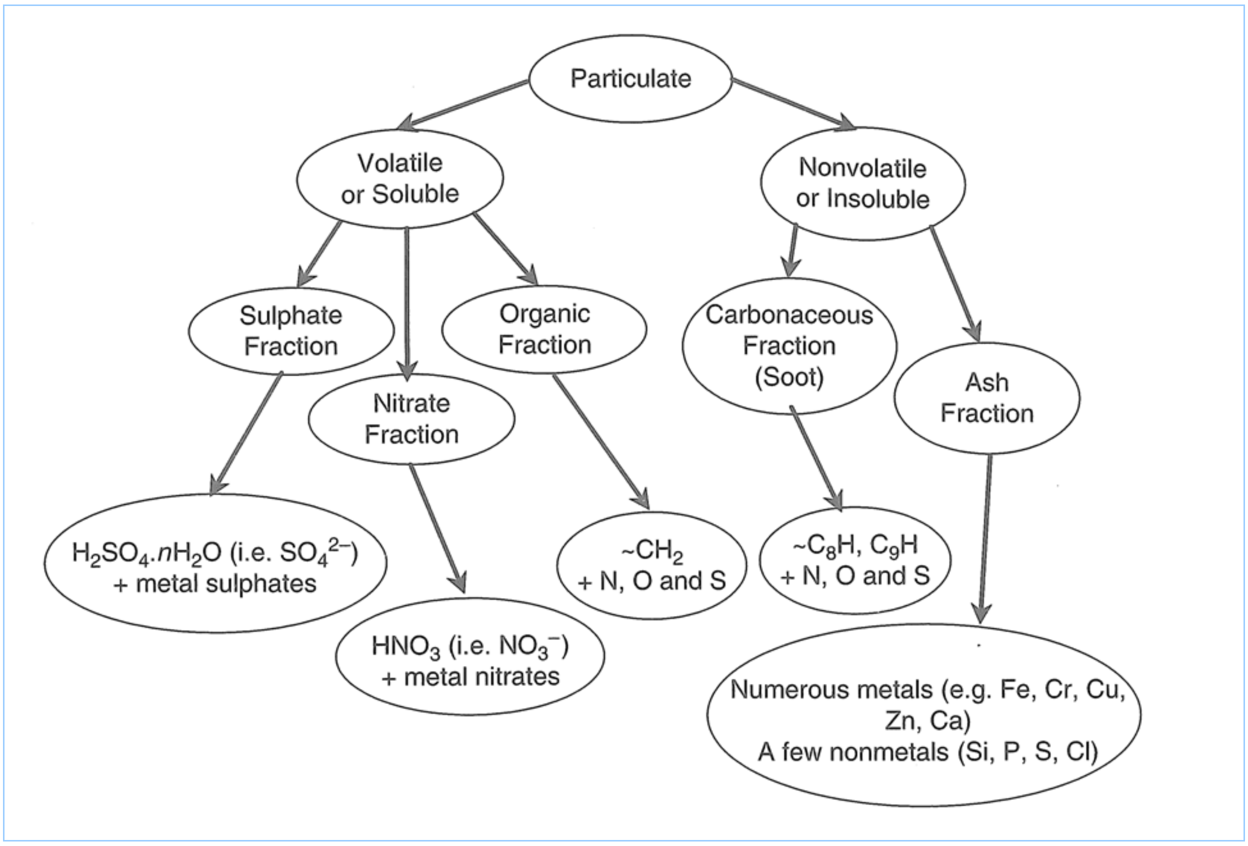


Figure 2-4: Conceptual model of diesel particulate matter composition

The sizes of DPM that are of greatest health concern are in the categories of fine (~$PM_{2.5}$), and ultra-fine particles (~$PM_{0.1}$) (USEPA, 2013e).

Ultra-fine particles (UFP) or $PM_{0.1,}$ broadly corresponds to the Nucleation plus Aitken modes, which equally contain most of the particles by number. Fine particles are most often associated with $PM_{2.5}$, which mainly includes the Nucleation, Aitken and Accumulation modes, with most of the particles by mass residing in the Accumulation mode. Coarse particles are mainly in $PM_{10\text{-}2.5}$. Figure 2-5 shows the number distribution for UFP and the volume distribution for fine and coarse particles, where dashed lines refer to values in individual modes and solid lines to their sum (USEPA, 2009a).

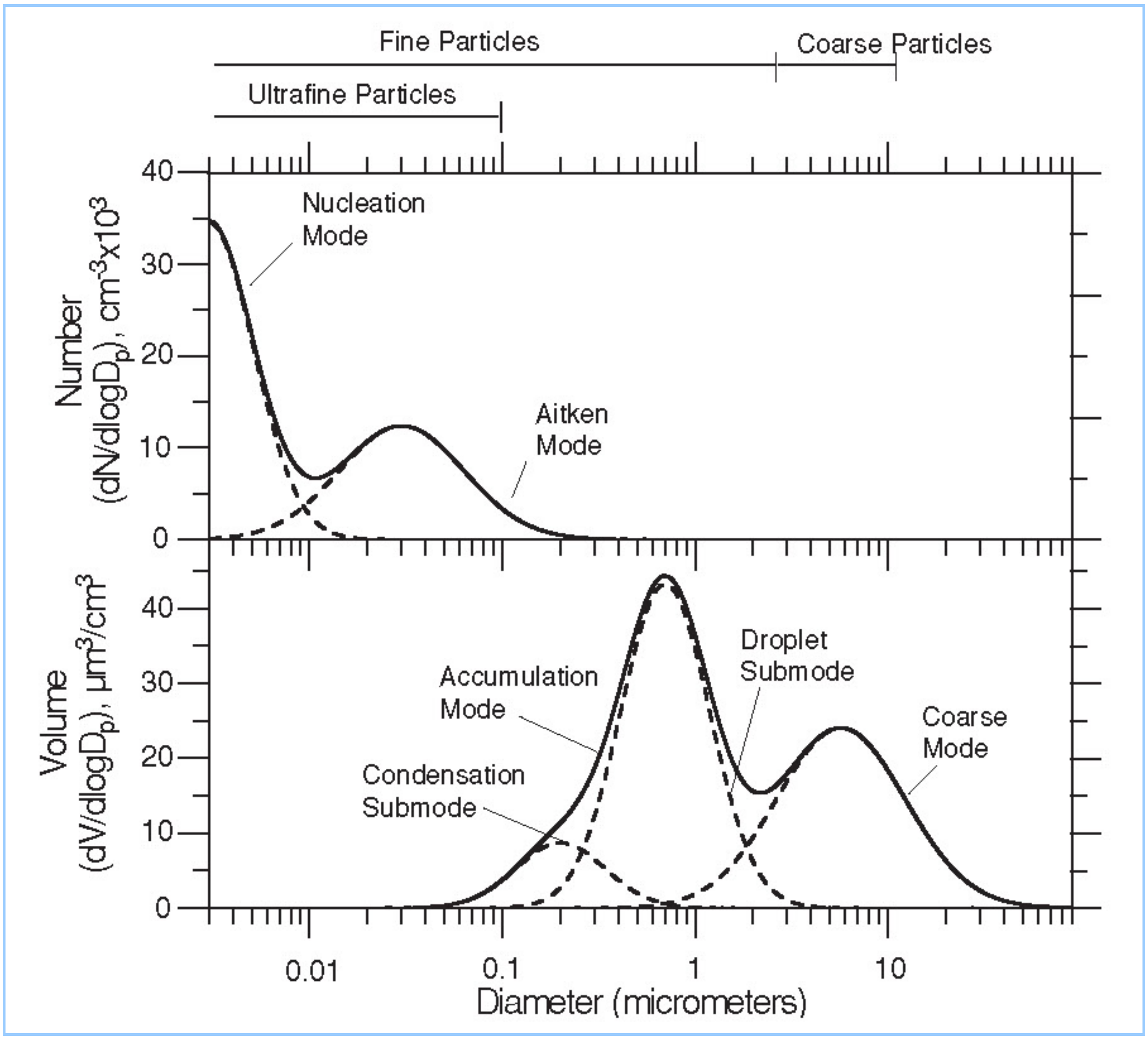


Figure 2-5: Particle size distributions by number and volume

2.2 Environmental Impacts of Particulate Matter

This section summarises the visibility impairment, environmental effects and amenity impacts associated with primary and secondary PM.

2.2.1 Visibility impairment

One of the most basic forms of air pollution is known as haze and this degrades visibility in many urban and rural areas throughout NSW. Haze is caused when sunlight is scattered off PM in ambient air, which reduces the clarity and colour of what the human eye can see. Visibility impairment is more pronounced during humid weather conditions. Fine particles ($PM_{2.5}$) are the main cause of reduced visibility (USEPA, 2013c).

Concerns about PM emissions from coal mines often relate to the visible dust plumes generated by different sources. Visible dust is usually seen during short term episodes of high emissions, which may be caused by: trucks travelling down an unwatered haul road, under high load or up an incline; high wind gusts on exposed land surfaces; loading and unloading overburden during hot, dry and windy conditions; and/or during blasting.

2.2.2 Environmental effects

Particulate matter can be carried over long distances by wind and then settle on either land and/or water. The effects of settling may include: making lakes and streams acidic; changing the nutrient balance in coastal waters and large river basins; depleting the nutrients in soil; damaging sensitive natural vegetation and farm crops; and affecting the diversity of ecosystems (USEPA, 2013d).

Oxides of nitrogen, SO_2 and NH_3 from non-road diesel exhaust emissions react in the atmosphere to form inorganic nitrate and sulfate compounds, which are a form of secondary PM pollution and largely responsible for environmental effects.

2.2.3 Amenity impacts

Particulate matter can stain and damage stone and other materials, including culturally important objects such as statues and monuments. Deposition of PM can contribute to: corrosion of metals; deterioration of paint; stain and damage to stone; and soiling of buildings, which leads to increased maintenance costs. These impacts can significantly reduce the value of structures, buildings, bridges, cultural objects and cars. Amenity impacts caused by PM are usually associated with coarse particles ($PM_{10-2.5)}$ and particles larger than PM_{10} (PM_{30-10}) (USEPA, 2013d).

In terms of coal mines, amenity impacts tend to occur when PM is deposited on buildings/houses, cars and laundry. Particulate matter deposited on roofs can be transferred to water tanks during rain, which can result in contaminated drinking water. Fugitive PM emissions from the mining and processing of coal are largely responsible for amenity impacts, rather than those from non-road diesel exhaust emissions.

2.3 Health Effects of Particulate Matter

This section summarises the health effects associated with fine, coarse and DPM and ambient air quality standards and criteria for PM, which apply across Australia and NSW.

2.3.1 Fine and coarse particulate matter

The size of PM is directly linked to its potential for causing health problems. Generally, it is thought that fine particles ($PM_{2.5}$) (e.g. smoke and haze) may be of a greater health concern than larger particles as they can penetrate deep into the lungs and some may even enter the bloodstream. However, inhalable coarse particles ($PM_{2.5-10}$) (e.g. windborne dust and mining/quarrying) are also associated with adverse health effects (USEPA, 2013d).

Numerous scientific studies have linked PM exposure to a variety of lung and heart problems, including (USEPA, 2009a):

- premature death in people with heart or lung disease
- nonfatal heart attacks
- irregular heartbeat
- aggravated asthma
- decreased lung function
- increased respiratory symptoms (leading to hospital admissions and emergency room visits), such as irritation of the airways, coughing or difficulty breathing.

People with heart or lung diseases, children and older adults are the most likely to be affected by PM exposure. However, even healthy individuals may experience temporary symptoms from exposure to elevated levels of PM. Both long (over years) and short term (hours or days) PM exposure has been linked to health problems. While there is no safe level of exposure for PM, the risk of health impacts decreases with lower levels of exposure (WHO, 2006).

2.3.2 Diesel particulate matter

In 1988, the International Agency for Research on Cancer (IARC), which is part of the World Health Organization (WHO), classified diesel exhaust as probably carcinogenic to humans (Group 2A) (IARC, 1988). A Working Group which reviews and recommends future priorities for the IARC Monographs Program had recommended diesel exhaust as a high priority for re-evaluation since 1998.

There has been mounting concern about the cancer causing potential of diesel exhaust, particularly based on the findings of recent epidemiological studies. The results of a large US National Cancer Institute (NCI)/National Institute for Occupational Safety and Health (NIOSH) study of occupational exposure to diesel exhaust in the non-metal mining industry showed an increased risk of death from lung cancer in exposed workers (Silverman et al., 2012).

In 2012, the IARC Working Group stated *'The scientific evidence was compelling and the Working Group's conclusion was unanimous: diesel engine exhaust causes lung cancer in humans. Given the additional health impacts from diesel particulates, exposure to this mixture of chemicals should be reduced worldwide'* (IARC, 2012). This position was based on the findings of a study on diesel exhaust exposure in the non-metal mining industry (Attfield et. al., 2012).

IARC has now classified diesel engine exhaust as carcinogenic to humans (Group 1), based on sufficient evidence that exposure is associated with an increased risk of lung cancer (IARC, 2012).

2.3.3 Outdoor air pollution

On 24 October 2014, IARC *stated 'In October 2013, 24 experts from 11 countries met at the IARC, Lyon, France, to assess the carcinogenicity of outdoor air pollution'. The latest review identified that air pollution as a whole, as well as the small particles that make up part of air pollution (measures of* $PM_{2.5}$ *and* PM_{10}*, particulate matter of different sizes, are used in monitoring air pollution and in epidemiological studies) cause cancer'* (IARC, 2013). *'This assessment was the last in a series that began with specific combustion products and sources of air pollution and concluded with the complex mixture that contains all of them. The results of this most recent assessment will be published as volume 109 of the IARC Monographs'* (Loomis et. al., 2013).

The IARC has now identified that air pollution as a whole (including the small particles that make up part of air pollution) causes cancer (IARC, 2013).

2.3.4 Ambient air quality standards, goals and assessment criteria for particulate matter

The *National Environment Protection (Ambient Air Quality) Measure* (Ambient Air Quality NEPM) establishes ambient air quality standards for six key pollutants (CO; lead; nitrogen dioxide (NO_2); PM_{10}; ground-level ozone (O_3); SO_2 and $PM_{2.5}$) and provides jurisdictions with a standard way of monitoring and reporting on ambient air quality (NEPC, 2003).

The Ambient Air Quality NEPM requires that each jurisdiction provides NEPC with an annual report that assesses compliance with the air quality standards (NEPC, 2002 – 2010). The Ambient Air Quality NEPM standards and goals for PM are presented in Table 2-2.

Table 2-2: Ambient Air Quality NEPM standards and goals for particulate matter

Pollutant	Averaging Period	Maximum Concentration	Goal within 10 years (Maximum allowable exceedances)
Particles as PM_{10}	1 day	50 µg/m^3	5 days a year
*Particles as $PM_{2.5}$	1 day 1 year	25 µg/m^3 8 µg/m^3	Gather sufficient data nationally to facilitate a review of the ARS as part of the review of this Measure
*Advisory Reporting Standard means a health-based standard to assess the results of monitoring for particles as $PM_{2.5}$. These standards do not have a timeframe for compliance			

The *Approved Methods for the Modelling and Assessment of Air Pollutants in NSW* (Approved Methods for Modelling) (DEC, 2005b) lists the statutory methods to assess air pollutant emissions from stationary sources and is referred to in Part 5 (Air Impurities Emitted from Activities and Plant) of the *Protection of the Environment Operations (Clean Air Regulation) 2010* (POEO Clean Air Regulation) (PCO, 2011a). The Approved Methods for Modelling may also be referred to in conditions attached to statutory instruments, such as environment protection licences (EPL) or Notices issued under the *Protection of the Environment Operations Act 1997* (POEO Act) (PCO, 2010).

The Approved Methods for Modelling includes assessment criteria for criteria pollutants, air toxics and odorous air pollutants, which are used to evaluate the impacts on:

- human health, including sensitive populations such as asthmatics, children and the elderly
- amenity, including visibility impairment and private property.

The assessment criteria are used to assess the total impact of the proposal including the incremental impact of emissions plus background air quality to ensure the cumulative impacts of all sources in the local area do not pose unacceptable risk to human health and amenity of local residents.

The Approved Methods for Modelling assessment criteria for PM_{10}, TSP and deposited dust are presented in Table 2-3. The Approved Methods for Modelling does not include assessment criteria for $PM_{2.5}$.

Table 2-3: Approved Methods for Modelling assessment criteria for particulate matter

Pollutant	Averaging period	Assessment criterion		Impact type
PM_{10}	24 hour	*50 µg/m^3		human health
PM_{10}	Annual	*30 µg/m^3		human health
Total Suspended Particulate (TSP)	Annual	*90 µg/m^3		amenity
Deposited Dust	Annual	#2 g/m^2/month	*4 g/m^2/month	Amenity
*Total impact (predicted incremental impact plus background) #The incremental impact (predicted impacts due to the source alone)				

2.4 Health Costs of Particulate Matter

This section describes the damage costs approach and unit damage costs data used in the Cost Benefit Analysis (CBA) (refer to Section 8 for further details).

2.4.1 Introduction

More Australians die each year from air pollution (3,056) than from road traffic accidents (1,662) (AIHW, 2007). Many more Australians, primarily children, the elderly and those with respiratory conditions, live with impaired health and quality of life due to air pollution. Air pollution causes 27,519 disability-adjusted life years (DALY)) (AIHW, 2007).

Although air quality in NSW is relatively good by international standards and has been steadily improving over time (DECCW, 2010), it still imposes major costs on NSW communities. The health costs of air pollution in the NSW Greater Metropolitan Region (GMR) have been calculated at $4.7 billion per annum (DEC, 2005a). Transport emissions alone have been calculated to have health costs of $2.7 billion per year in Australia (BTRE, 2005). The most significant health costs result from exposure to PM and to a lesser extent, O_3.

2.4.2 Damage costs approach

To ensure that CBA value health impacts in a consistent way, PAEHolmes conducted an international review and developed a methodology for PM in Australia (PAEHolmes, 2013) as part of the *National Plan for Clean Air* (SCEW, 2013). The methodology is:

- simple, robust and capable of being updated to reflect changes in the health evidence
- equally applicable when evaluating the impacts of emissions reduction measures at a State, Territory or Commonwealth level.

Based on the findings of the international review (PAEHolmes, 2013), PAEHolmes concluded the best approach would be to transfer damage cost values from the UK Department of Environment, Food and Rural Affairs (DEFRA) (DEFRA, 2013). The UK DEFRA damage costs in pounds sterling (2010 prices) were converted to Australian dollars (2011 prices) by accounting for differences in the Value of a Life Year (VOLY), currency, inflation and population density between the UK and Australia (PAEHolmes, 2013).

PAEHolmes developed unit damage costs for specific geographical areas of Australia using a standardised method where the location of emissions is related to a population-weighted exposure. The method uses the ABS Significant Urban Area (SUA) structure (ABS, 2012), where each SUA is assigned a unique unit damage cost by accounting for differences in population density (PAEHolmes, 2013).

The 2011 calendar year unit damage costs for $PM_{2.5}$ by significant urban area (SUA) in NSW are presented in Table 2-4 (PAEHolmes, 2013). The 2011 calendar year unit damage costs for $PM_{2.5}$ by suburb/town (where coal mines in NSW are located), which have been used in this project are presented in Table 2-5. Australian Bureau of Statistics concordance tables (ABS, 2012) have been used to assign each suburb/town to the appropriate SUA.

Table 2-4: 2011 unit damage costs for $PM_{2.5}$ by significant urban area (SUA) in NSW

SUA name	Damage cost/tonne of $PM_{2.5}$ (2011 AUD)
Sydney	280,000
Central Coast	150,000
Wollongong	130,000
Port Macquarie	120,000
Forster – Tuncurry	110,000
Newcastle – Maitland	110,000
Goulburn	93,000
Ballina	90,000
Lismore	89,000
Griffith	89,000
Ulladulla	85,000
Cessnock	82,000
Wagga Wagga	76,000
Orange	71,000
Nelson Bay – Corlette	61,000
Dubbo	52,000
Kurri Kurri – Weston	50,000
Grafton	48,000
Batemans Bay	47,000
Nowra-Bomaderry	46,000
St Georges Basin - Sanctuary Point	46,000
Tamworth	45,000
Bathurst	43,000
Taree	38,000
Albury – Wodonga	37,000
Coffs Harbour	36,000
Singleton	36,000
Broken Hill	30,000
Lithgow	29,000
Bowral – Mittagong	23,000
Armidale	23,000
Morisset – Cooranbong	18,000
Parkes	13,000
Muswellbrook	13,000
Camden Haven	8,400
Not in any Significant Urban Area (NSW)	360

Table 2-5: 2011 unit damage costs for $PM_{2.5}$ by suburb/town and significant urban area (SUA) in NSW

Damage cost/tonne of $PM_{2.5}$ (2011 AUD)	SUA name									
Suburb/Town	**Central Coast**	**Wollongong**	**Newcastle - Maitland**	**Cessnock**	**Singleton**	**Lithgow**	**Bowral - Mittagong**	**Morisset - Cooranbong**	**Muswellbrook**	**Not in any Significant Urban Area (NSW)**
APPIN										360
ASHTONFIELD			110,000							
AWABA			110,000							
BAAN BAA										360
BLACK HILL			110,000							
BOGGABRI										360
CAMBERWELL					36,000					
CAPERTEE						29,000				
CHAIN VALLEY BAY	150,000									
CHARBON										360
CULLEN BULLEN						29,000				
DORA CREEK								18,000		
DOYALSON	150,000									
FASSIFERN			110,000							
GUNNEDAH										360
HELENSBURGH		130,000								
LIDSDALE						29,000				
LITHGOW						29,000				
MAITLAND			110,000							
MEDWAY							23,000			
MOUNT KEMBLA		130,000								
MOUNT THORLEY					36,000					

Damage cost/tonne of $PM_{2.5}$ (2011 AUD)	SUA name									
Suburb/Town	**Central Coast**	**Wollongong**	**Newcastle - Maitland**	**Cessnock**	**Singleton**	**Lithgow**	**Bowral - Mittagong**	**Morisset - Cooranbong**	**Muswellbrook**	**Not in any Significant Urban Area (NSW)**
MUDGEE										360
MUSWELLBROOK									13,000	
NEWNES JUNCTION						29,000				
PELTON				82,000						
PORTLAND						29,000				
RAVENSWORTH					36,000				13,000	
RUSSELL VALE		130,000								
SEAHAMPTON			110,000							
SINGLETON					36,000					
STRATFORD										360
STROUD ROAD										360
TAHMOOR										360
TERALBA			110,000							
WANGI WANGI			110,000							
WARKWORTH					36,000					
WERRIS CREEK										360
WOLLONGONG		130,000								
WONGAWILLI		130,000								
WYBONG									13,000	

A map of significant urban areas (SUA) in NSW is shown in Figure 2-6 (ABS, 2012).

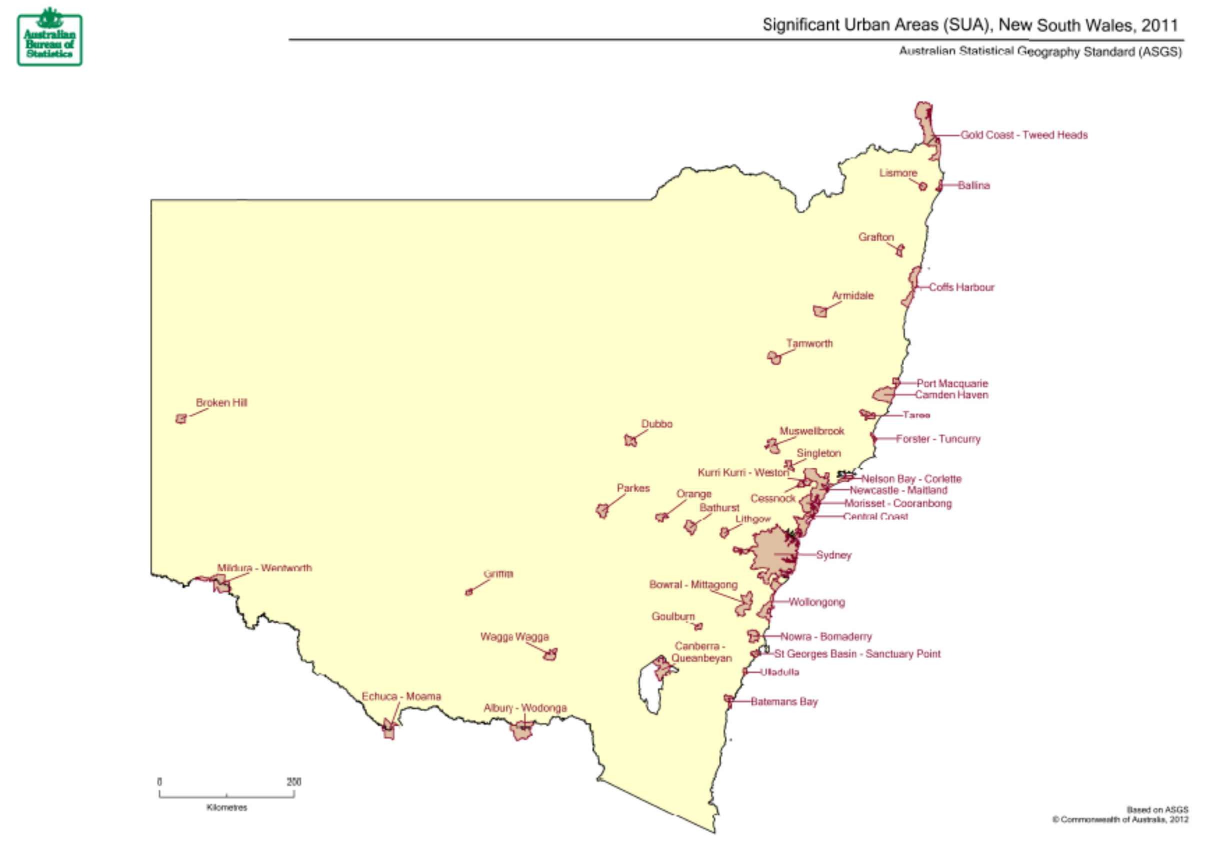


Figure 2-6: Map of significant urban areas (SUA) in NSW

2.4.3 Unit damage costs data used in Cost Benefit Analysis

Since the CBA findings presented in Section 8 refer to the 2012 base year, the unit damage costs in future calendar years (from 2013 to 2030) have been adjusted to the 2012 calendar year by accounting for:

- **(1) Population change** – Since population will change in future years, this will also affect population density. This CBA assumes the change in population density is proportional to the change in population. Unit damage costs in future years have been estimated by multiplying the 2011 calendar year unit damage costs by the proportional change in population in two steps.

  Firstly, Australian Bureau of Statistics (ABS) regional population growth data (ABS, 2013a) have been used to derive 2012 calendar year population growth factors for each significant urban area (SUA) in NSW. The 2012 ABS growth factors have then been multiplied by the 2011 unit damage costs developed by PAEHolmes (PAEHolmes, 2013) to estimate 2012 unit damage costs.

  Secondly, Department of Planning & Infrastructure (DP&I) NSW and Local Government Area (LGA) population projections data (DP&I, 2013) have been used to derive 2013 to 2030 calendar year population growth factors for each SUA in NSW. The 2013 to 2030 DP&I growth factors have then been multiplied by the 2012 unit damage costs to estimate 2013 to 2030 unit damage costs.

- **(2) Willingness to pay for health care** – Willingness to pay (WTP) for health care will continue to rise in line with economic growth. This CBA assumes the change in health care costs is consistent with the long term growth in Gross Domestic Product (GDP) of 2%. This assumption is based on the findings of the PAEHolmes international review (PAEHolmes, 2013) and the UK DEFRA air quality damage cost guidance (DEFRA, 2013). The compound interest formula has been used to derive 2012 to 2030 calendar year unit damage costs from the 2011 calendar year estimates (PAEHolmes, 2013).

- **(3) Time value of money** - The time value of money is based on the principle that a given currency amount of money at present has a different buying power in the future. Unit damage costs in future years are expressed for the present year by applying a discount rate. This CBA assumes a discount rate of 7%, which is based on NSW Treasury economic appraisal guidance (NSW Treasury, 2007a, 2007b & 2007c). The compound interest formula has been used to express 2013 to 2030 calendar year unit damage costs as 2012 calendar year present value (PV) estimates.

For each SUA in NSW, the unit damage costs in future years have been adjusted to 2012 calendar year PV estimates by accounting for (1) population change, (2) willingness to pay for health care and (3) the time value of money using Equation 1.

$$UDC_n = UDC_{2012} \text{ x } (POP_n/POP_{2012}) \text{ x } (1+GDP/100)^{(n-2012)}/(1+DR/100)^{(n-2012)}$$ **Equation 1**

where:
UDC = Unit damage cost in AUD
POP = Population in each significant urban area (SUA) in NSW
GDP = Long term growth rate in Gross Domestic Product (2%)
DR = Discount rate (7%)
n = calendar year from 2012 to 2030

The 2012 to 2030 calendar year unit damage costs for $PM_{2.5}$ in 2012 AUD by SUA in NSW, which have been used in this project, are presented in Table 2-6.

Table 2-6: 2012 to 2030 unit damage costs for $PM_{2.5}$ by significant urban area (SUA) in NSW (2012 AUD)

SUA name	Damage cost/tonne of $PM_{2.5}$ (2012 AUD)																		
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Sydney	290,515	281,626	272,932	264,437	256,139	248,379	240,785	233,359	226,101	219,011	211,935	205,043	198,331	191,799	185,445	179,241	173,213	167,356	161,669
Central Coast	154,569	148,843	143,314	137,976	132,825	127,988	123,314	118,797	114,432	110,217	106,092	102,112	98,273	94,569	90,997	87,515	84,159	80,927	77,812
Wollongong	133,483	128,087	122,905	117,926	113,145	108,833	104,677	100,672	96,813	93,094	89,446	85,936	82,559	79,310	76,184	73,144	70,223	67,415	64,716
Port Macquarie	123,936	119,609	115,416	111,353	107,418	103,479	99,674	95,998	92,448	89,021	85,489	82,092	78,827	75,687	72,669	69,672	66,796	64,037	61,390
Forster - Tuncurry	113,839	110,082	106,427	102,873	99,420	95,518	91,764	88,152	84,678	81,336	77,926	74,656	71,523	68,519	65,640	62,849	60,176	57,616	55,163
Newcastle - Maitland	113,969	110,330	106,782	103,325	99,958	96,601	93,339	90,172	87,096	84,112	81,203	78,383	75,649	72,999	70,432	67,921	65,491	63,139	60,865
Goulburn	95,195	91,066	87,116	83,335	79,718	76,626	73,649	70,783	68,024	65,368	62,687	60,114	57,645	55,275	53,001	50,819	48,725	46,715	44,787
Ballina	92,610	89,055	85,629	82,330	79,151	75,913	72,805	69,821	66,957	64,209	61,459	58,827	56,306	53,892	51,581	49,302	47,124	45,042	43,051
Lismore	91,026	87,007	83,164	79,491	75,980	72,623	69,414	66,346	63,414	60,610	57,778	55,078	52,504	50,051	47,712	45,442	43,281	41,222	39,261
Griffith	89,273	83,665	78,386	73,417	68,742	64,965	61,391	58,009	54,809	51,781	48,917	46,207	43,644	41,219	38,926	36,757	34,705	32,765	30,931
Ulladulla	87,152	83,510	80,018	76,670	73,460	70,454	67,568	64,798	62,140	59,588	57,095	54,704	52,412	50,215	48,109	46,064	44,104	42,228	40,430
Cessnock	84,787	81,919	79,133	76,429	73,805	71,334	68,933	66,601	64,336	62,137	59,984	57,896	55,873	53,912	52,012	50,141	48,332	46,582	44,890
Wagga Wagga	78,175	75,147	72,231	69,424	66,721	64,159	61,690	59,313	57,022	54,817	52,755	50,766	48,848	46,999	45,215	43,459	41,768	40,141	38,574
Orange	73,007	70,154	67,409	64,768	62,226	59,780	57,426	55,163	52,985	50,891	48,876	46,939	45,076	43,284	41,562	39,888	38,280	36,735	35,251
Nelson Bay - Corlette	63,629	62,000	60,383	58,783	57,200	55,359	53,565	51,818	50,118	48,463	46,842	45,267	43,736	42,250	40,807	39,371	37,979	36,632	35,328
Dubbo	53,302	51,061	48,913	46,854	44,881	43,072	41,335	39,666	38,062	36,522	35,042	33,622	32,257	30,947	29,688	28,441	27,246	26,101	25,003
Kurri Kurri - Weston	51,699	49,950	48,252	46,603	45,003	43,496	42,032	40,610	39,229	37,889	36,576	35,303	34,069	32,873	31,715	30,574	29,470	28,403	27,372
Grafton	49,017	46,781	44,647	42,611	40,667	38,962	37,327	35,761	34,259	32,819	31,368	29,981	28,656	27,388	26,177	24,982	23,841	22,752	21,713
Batemans Bay	48,536	46,836	45,189	43,594	42,049	40,410	38,833	37,315	35,854	34,448	33,063	31,733	30,454	29,226	28,046	26,874	25,751	24,674	23,641
Nowra-	47,164	45,193	43,304	41,492	39,755	38,128	36,566	35,067	33,629	32,248	30,898	29,605	28,364	27,175	26,036	24,929	23,868	22,853	21,880

SUA name	**Damage cost/tonne of $PM_{2.5}$ (2012 AUD)**																		
	2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Bomaderry																			
St Georges Basin - Sanctuary Point	47,164	45,193	43,304	41,492	39,755	38,128	36,566	35,067	33,629	32,248	30,898	29,605	28,364	27,175	26,036	24,929	23,868	22,853	21,880
Tamworth	46,293	44,504	42,782	41,123	39,526	38,025	36,579	35,184	33,840	32,545	31,287	30,076	28,910	27,787	26,705	25,641	24,619	23,635	22,690
Bathurst	44,586	43,194	41,835	40,508	39,214	37,936	36,691	35,480	34,301	33,156	32,029	30,935	29,873	28,843	27,844	26,865	25,916	24,997	24,108
Taree	38,905	37,226	35,618	34,080	32,607	31,224	29,898	28,628	27,411	26,246	25,059	23,927	22,845	21,812	20,826	19,868	18,955	18,084	17,252
Albury - Wodonga	38,030	36,529	35,085	33,697	32,361	31,065	29,819	28,622	27,472	26,367	25,333	24,338	23,381	22,461	21,575	20,716	19,889	19,095	18,332
Coffs Harbour	37,010	35,557	34,159	32,814	31,520	30,300	29,125	27,994	26,905	25,856	24,783	23,753	22,766	21,819	20,910	20,014	19,156	18,334	17,548
Singleton	37,095	35,719	34,391	33,109	31,871	30,652	29,478	28,346	27,256	26,206	25,175	24,183	23,229	22,312	21,429	20,565	19,735	18,937	18,171
Broken Hill	30,151	28,315	26,584	24,953	23,417	22,096	20,847	19,666	18,551	17,496	16,520	15,596	14,723	13,898	13,117	12,363	11,652	10,979	10,344
Lithgow	29,523	28,089	26,725	25,427	24,192	23,084	22,026	21,017	20,055	19,136	18,242	17,389	16,577	15,802	15,064	14,360	13,689	13,049	12,439
Bowral - Mittagong	23,623	22,675	21,764	20,888	20,047	19,222	18,431	17,672	16,944	16,245	15,555	14,895	14,262	13,656	13,075	12,509	11,967	11,448	10,952
Armidale	23,849	23,106	22,380	21,672	20,981	20,190	19,428	18,692	17,983	17,300	16,652	16,027	15,425	14,843	14,282	13,742	13,220	12,718	12,233
Morisset - Cooranbong	18,435	17,645	16,889	16,164	15,471	14,851	14,256	13,683	13,134	12,605	12,093	11,601	11,128	10,675	10,239	9,816	9,411	9,022	8,649
Parkes	13,260	12,640	12,050	11,487	10,950	10,466	10,003	9,561	9,138	8,734	8,337	7,957	7,595	7,250	6,920	6,614	6,321	6,041	5,774
Muswellbrook	13,390	12,889	12,405	11,938	11,487	11,053	10,634	10,230	9,841	9,466	9,094	8,736	8,392	8,061	7,743	7,437	7,142	6,859	6,586
Camden Haven	8,676	8,373	8,079	7,795	7,519	7,244	6,977	6,720	6,471	6,231	5,984	5,746	5,518	5,298	5,087	4,877	4,676	4,483	4,297
Not in any Significant Urban Area (NSW)	370	355	341	327	314	301	289	277	265	254	244	233	224	214	205	196	188	180	172

3 AMBIENT AIR QUALITY AND PARTICULATE MATTER POLLUTION SOURCES IN NSW

This section lists the air pollutants of greatest concern in NSW, a summary of ambient air quality across NSW and around communities located near coal mines, sources of primary particulate matter (PM) pollution derived from air emissions inventories and the composition of PM in ambient air at communities situated close to coal mines.

3.1 Ambient Air Quality Measurements

This section provides a summary of ambient air quality across NSW and around communities located near coal mines.

3.1.1 *Current Air Quality in NSW and NSW State of the Environment 2012*

Air quality in NSW is generally good by international standards and has been steadily improving over time. In 1998, ambient air quality standards and goals for six common pollutants were included in the *National Environment Protection (Ambient Air Quality) Measure* (Ambient Air Quality NEPM) (NEPC, 2003). *Current Air Quality in New South Wales* and *New South Wales State of the Environment 2012* (DECCW, 2010 & EPA, 2012b) show that ambient levels of carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) are all consistently below their respective Ambient Air Quality NEPM standards in most areas. However, ambient levels of ground-level ozone (O_3) in urban areas and particulate matter (PM_{10} & $PM_{2.5}$)) in both rural and urban areas can exceed Ambient Air Quality NEPM standards, so they are the pollutants of greatest concern in those regions (DECCW, 2010 & EPA, 2012b).

The Office of Environment and Heritage (OEH) operates a comprehensive air quality monitoring network throughout NSW, which presently includes 40 sites in the Sydney (15), Illawarra (3), Upper Hunter (14), Lower Hunter (3), Central Coast (1) and Rural (4) regions (OEH, 2013a). Each of these sites monitors air quality for those pollutants in Ambient Air Quality NEPM which are an issue in that region.

Historical monitoring data demonstrates that ambient levels of CO (1982 to 2009), Pb (1990 to 2004) and NO_2 (1980 to 2009) have been steadily declining over time (DECCW, 2010).

Ambient levels of SO_2 (1994 to 2009) have largely remained steady (except near major industrial sources) (DECCW, 2010).

Figure 3-1 shows that:

- Between 1994 and 2011 in the Greater Metropolitan Region (GMR), up to ~25 exceedance days (2002 maximum in Lower Hunter and Sydney regions) of the 24-hour average Ambient Air Quality NEPM standard for PM_{10} were recorded (EPA, 2012b); and
- Similarly, from 2002 to 2011 in Rural regions, up to ~35 exceedance days (2006 maximum in Wagga Wagga) of the 24-hour average Ambient Air Quality NEPM standard for PM_{10} were recorded (EPA, 2012b).

Ambient particulate matter ((PM_{10}) (1994 to 2009) and $PM_{2.5}$ (1997 to 2009)) levels show little trend over time with the highest levels recorded during warmer months, dust storms and bushfire events (DECCW, 2010). Figure 3-2 shows the seasonal distribution of exceedences of the Ambient Air

Quality NEPM standard for 24-hour average PM_{10} in the GMR (1994 to 2011) and rural regions (2002 to 2011) (EPA, 2012b).

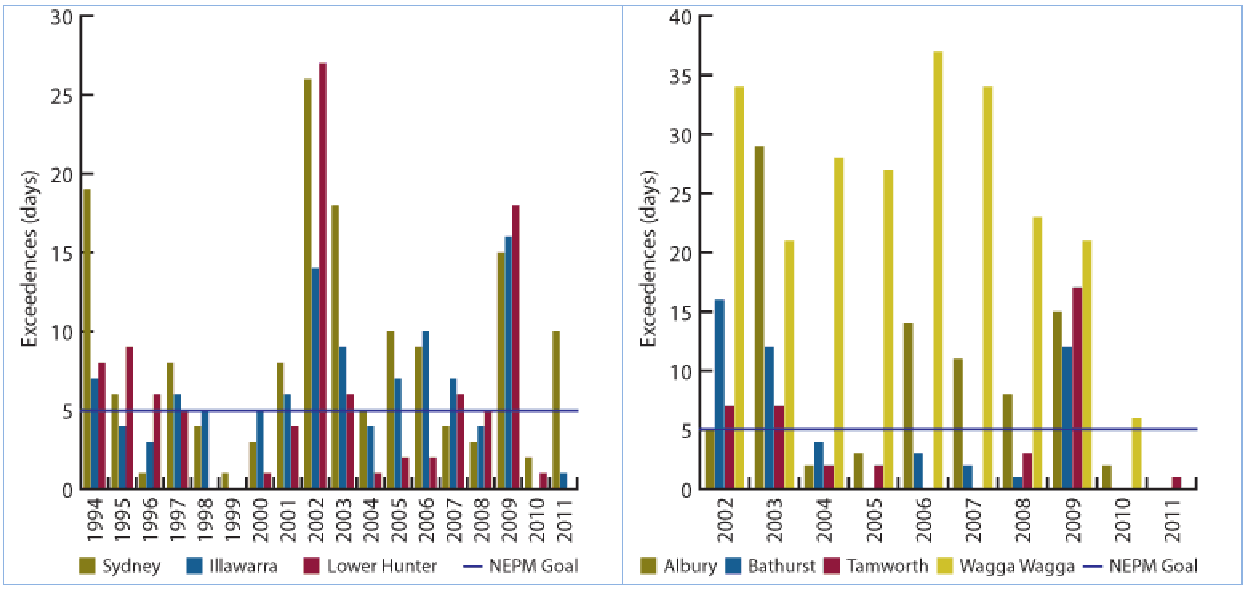


Figure 3-1: Exceedences of the Ambient Air Quality NEPM standard for 24-hour average PM_{10} in the GMR (left) and rural regions (right)

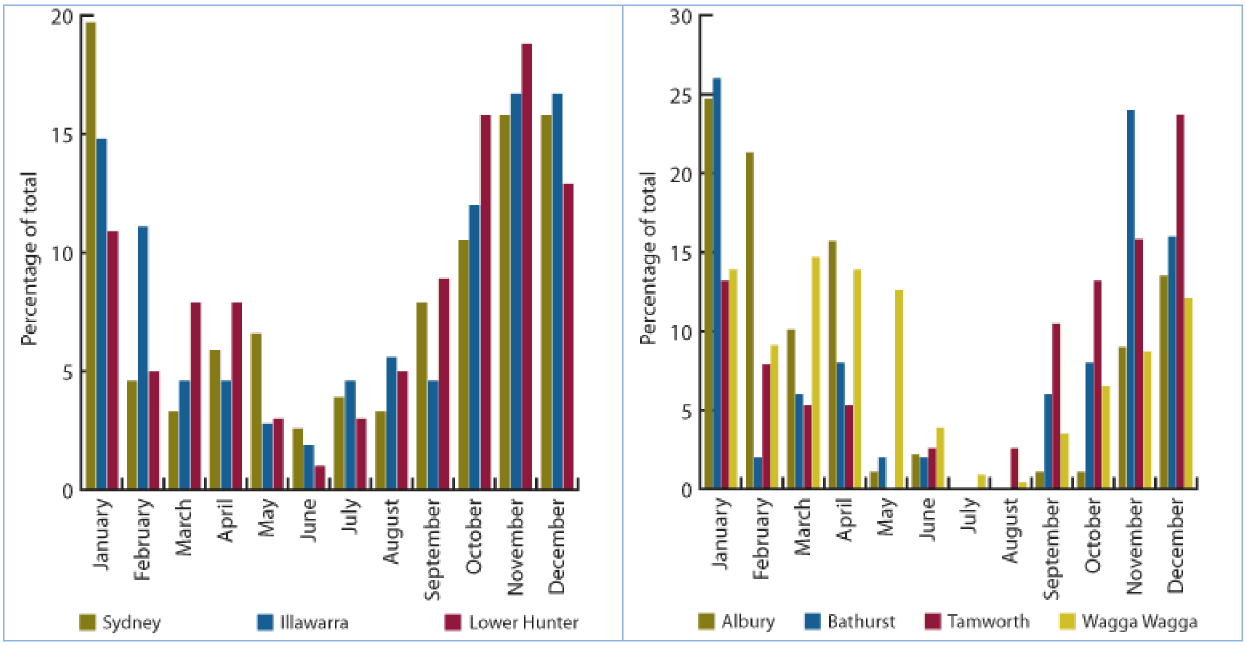


Figure 3-2: Seasonal distribution of exceedences of the Ambient Air Quality NEPM standard for 24-hour average PM_{10} in the GMR (left) and rural regions (right)

Between 1994 and 2011 in the Sydney region, the 1-hour and 4-hour average Ambient Air Quality NEPM standards for O_3 were exceeded up to 19 and 21 days per year in 2001 (EPA, 2012b). Over the same period in the Illawarra region, the 1-hour and 4-hour average Ambient Air Quality NEPM standards for O_3 were exceeded up to 7 days per year, while neither standard has been exceeded more than once per year since 1997 in the Lower Hunter region (EPA, 2012b). Between 1994 and 2008 background O_3 levels have trended up in the 90s, exhibited no trend in the early 00s and trended down in recent years (DECCW, 2010). Elevated levels and exceedances of Ambient Air Quality NEPM standards for O_3 largely result from year to year variations in meteorological patterns which are location specific (DECCW, 2010 & EPA, 2012b).

3.1.2 Compendium of Upper Hunter Ambient Air Quality Monitoring Data

The *Compendium of Upper Hunter Ambient Air Quality Monitoring Data* (OEH, 2011) presents a review of ambient levels of PM_{10}, SO_2 and NO_2 measured at industry monitoring sites from 2005 to 2009 and compares them against Ambient Air Quality NEPM standards. Ambient levels of $PM_{2.5}$ sourced from the Australian Nuclear Science and Technology Organisation (ANSTO) monitoring site at Muswellbrook are also presented for the same period. The data shows exceedances of the 24-hour average particulate matter (PM_{10} & $PM_{2.5}$) and 1-hour and 24-hour average SO_2 Ambient Air Quality NEPM standards near the residential areas of Muswellbrook and Singleton.

Between 2005 and 2009 in Muswellbrook, the Ambient Air Quality NEPM standards for:

- 24-hour average $PM_{2.5}$ was exceeded up to 3 days in 2009
- 24-hour average PM_{10} was exceeded up to 21 days in 2009
- 1-hour average SO_2 was exceeded up to 1 day in 2006 and 2007.

Between 2005 and 2009 in Singleton, the Ambient Air Quality NEPM standards for:

- 24-hour average PM_{10} was exceeded up to 12 days in 2008
- 1-hour and 24-hour average SO_2 were exceeded up to 1 day in 2005.

3.1.3 Hunter Valley Annual Air Quality 2012

Hunter Valley Annual Air Quality 2012 (OEH, 2013b) presents data from the Upper Hunter Air Quality Monitoring Network (UHAQMN). It shows that ambient levels of PM_{10} & $PM_{2.5}$ in the:

- Upper Hunter exceeded Ambient Air Quality NEPM standards during 2012
- Upper Hunter are higher than those at Beresfield, Newcastle and Wallsend in the Lower Hunter
- Lower Hunter are comparable with levels in Sydney and Wollongong.

A summary of ambient levels of particulate matter PM_{10} & $PM_{2.5}$ at major population centres in the Hunter Valley during 2012 (OEH, 2013b) shows:

- In the Upper Hunter, the highest 24-hour average PM_{10} level of 63.6 $\mu g/m^3$ was recorded at Singleton Central on 6 September. In the Lower Hunter, the highest 24-hour average PM_{10} level of 50.8 $\mu g/m^3$ was recorded at Beresfield on 6 September
- In the Upper Hunter, the Ambient Air Quality NEPM standard for 24-hour average PM_{10} was exceeded on 7 days (1 at Muswellbrook Central and 6 at Singleton Central). In the Lower Hunter, the Ambient Air Quality NEPM standard for 24-hour average PM_{10} was exceeded on 1 day (Beresfield)
- In the Upper Hunter, the highest 24-hour average $PM_{2.5}$ level of 26.4 $\mu g/m^3$ was recorded at Muswellbrook Central on 16 October. In the Lower Hunter, the highest 24-hour average $PM_{2.5}$ level of 22.4 $\mu g/m^3$ was recorded at Beresfield on 12 September
- In the Upper Hunter, the Ambient Air Quality NEPM standard for 24-hour average $PM_{2.5}$ was exceeded on 2 days (Muswellbrook Central), while the annual average standard was exceeded at the same location with a recorded level of 10.1 $\mu g/m^3$. In the Lower Hunter, the Ambient Air Quality NEPM standards for 24-hour and annual average $PM_{2.5}$ were not exceeded.

A summary of ambient levels of PM_{10} & $PM_{2.5}$ at small community sites in the Upper Hunter during 2012 (OEH, 2013b) shows:

- In the Upper Hunter, the highest 24-hour average PM_{10} level of 87.7 $\mu g/m^3$ was recorded at Maison Dieu on 1 November
- In the Upper Hunter, the Ambient Air Quality NEPM standard for 24-hour average PM_{10} was exceeded on 2 days (Bulga), 22 days (Camberwell), 19 days (Maison Dieu) and 1 day (Wybong).

3.2 Sources of Primary Particulate Matter Pollution

This section provides a summary of primary PM pollution sources derived from air emissions inventories.

3.2.1 NSW Greater Metropolitan Region Air Emissions Inventory

The NSW Greater Metropolitan Region (GMR) air emissions inventory (EPA, 2012a) is periodically compiled in order to:

- evaluate the effectiveness of existing air quality programs (e.g. *Protection of the Environment Operations (Clean Air Regulation) 2010* for EPA-licensed industry, service stations and residential wood heaters) (PCO, 2011a)
- identify new cost effective approaches for improving air quality (e.g. *Dust Stop* program for coal mines) (EPA, 2011)
- fulfil NSW State of the Environment reporting obligations (EPA, 2012b).

The 2008 calendar year inventory is a listing of over 1,000 substances released to atmosphere by natural and human-made sources within the GMR, which covers the metropolitan areas of Sydney, Newcastle and Wollongong and surrounding non-urban areas where 75% of the NSW population resides. Substances include:

- smog-forming oxides of nitrogen (NO_x) and volatile organic compounds (VOC)
- particulate matter (i.e. TSP, PM_{10} and $PM_{2.5}$) which causes impacts on amenity and human health
- several organic (e.g. dioxins) and metallic (e.g. chromium) substances which can have detrimental effects on humans and the environment.

Significant human-made sources of air pollution typically include service stations, domestic wood heaters, EPA-licensed coal mines and power stations, non-road diesel vehicles and equipment (non-road diesels) used at mines and quarries and registered buses, cars and trucks.

In the GMR, human-made sources are the major contributors of primary PM_{10} (73%) and $PM_{2.5}$ (81%) emissions. Similarly, in the Hunter region human-made sources are the most significant sources of primary PM_{10} (96%) and $PM_{2.5}$ (93%) emissions (EPA, 2012a). Comparisons of natural vs. human-made emissions and emissions by sector of primary PM_{10} and $PM_{2.5}$ in the GMR and Hunter region are presented in Figure 3-3. These emission estimates assume that:

- in the absence of certification information, all non-road vehicles and equipment have emissions control technology consistent with US Tier 0
- the sulfur content in diesel is 50 ppm, which is consistent with the 2008 calendar year requirements of the *Fuel Standard (Automotive Diesel) Determination 2001* (Attorney-General's Department, 2009a).

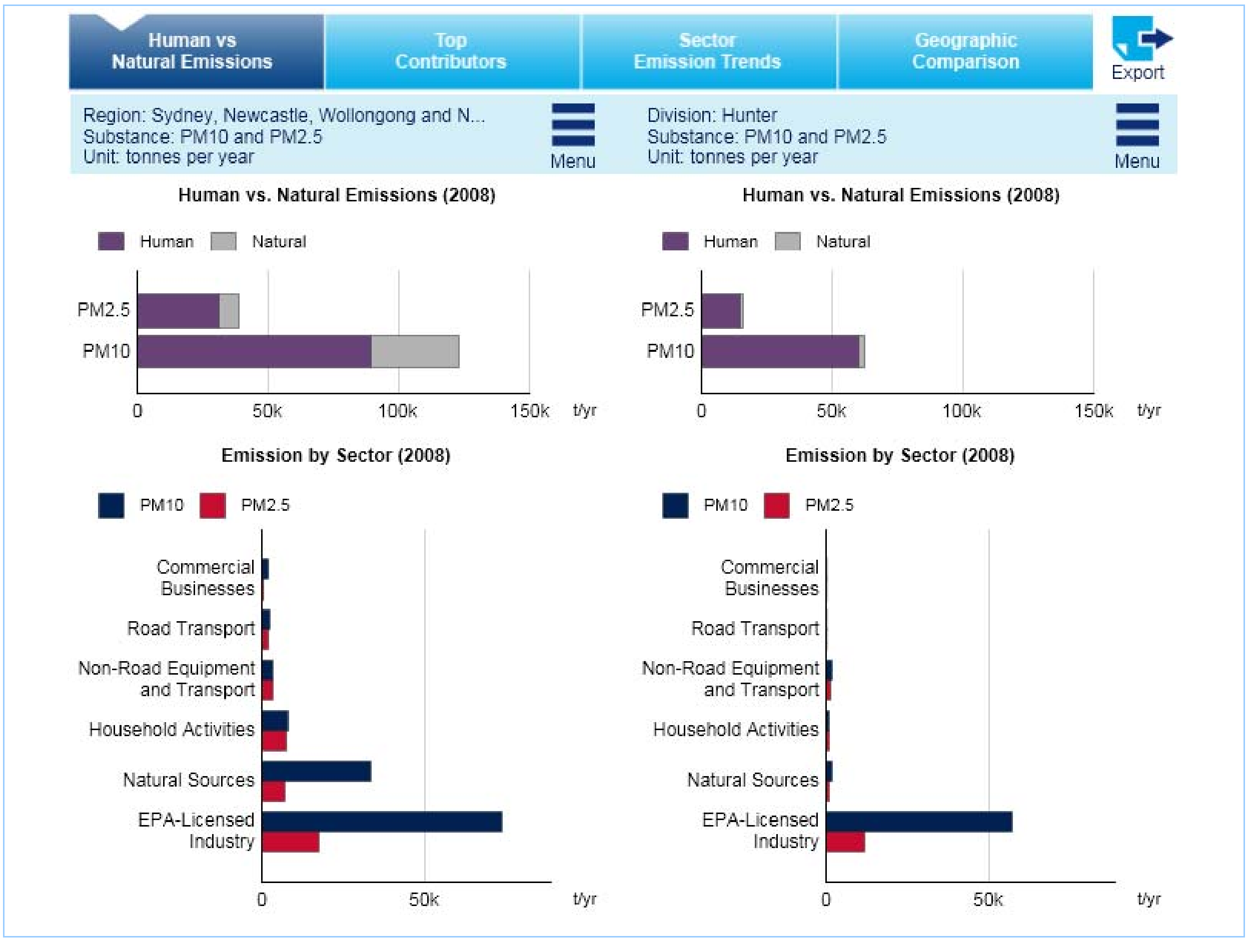


Figure 3-3: Natural vs. human-made emissions of primary PM_{10} and $PM_{2.5}$ in the GMR and Hunter region

Emissions of primary PM_{10} and $PM_{2.5}$ in the GMR are compared with the Hunter region by sector and presented in Table 3-1. The non-road equipment and transport sector includes air transport, commercial boats, commercial non-road vehicles and equipment, industrial (EPA-licensed) non-road vehicles and equipment, rail transport, recreational boats and shipping.

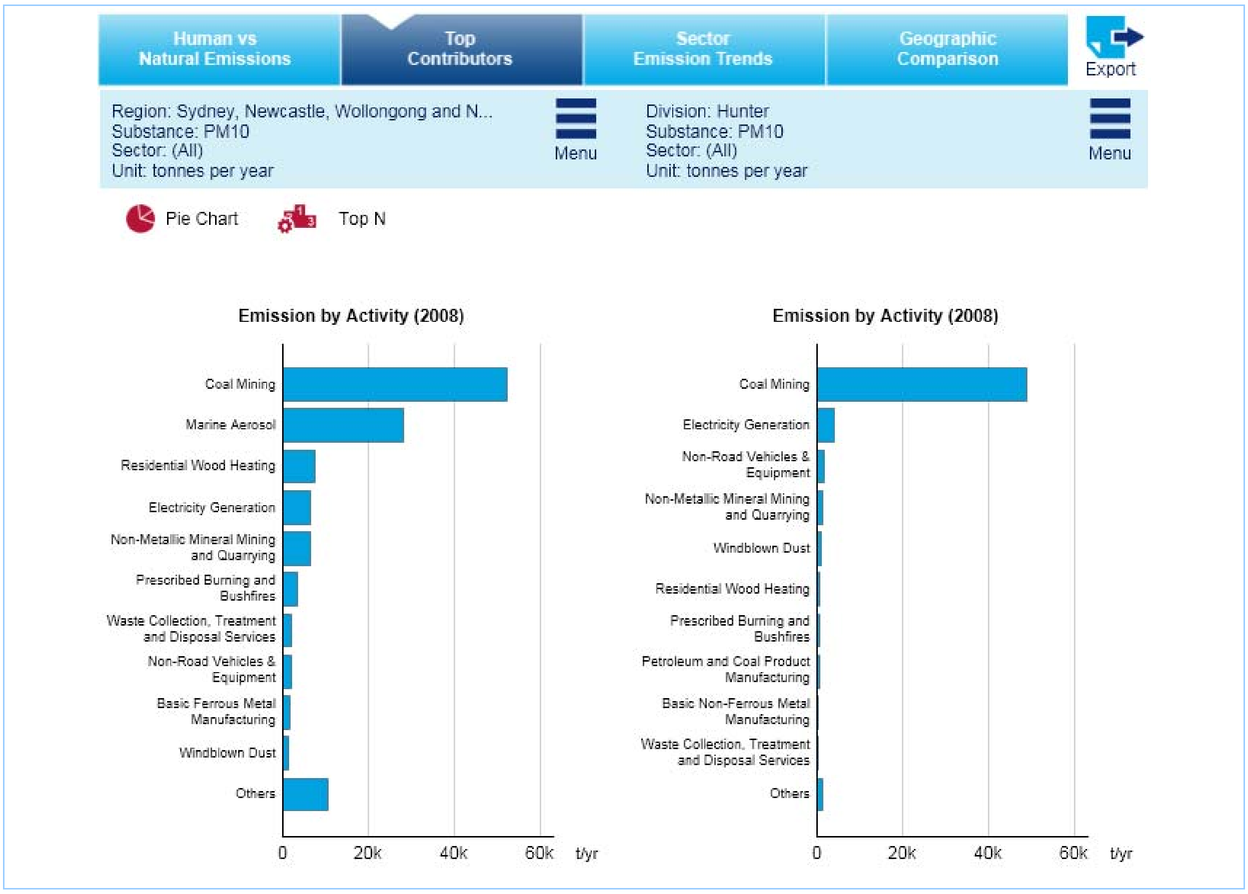
Table 3-1: Emissions of primary PM_{10} and $PM_{2.5}$ in the GMR vs. Hunter region by sector

2008 calendar year emissions (tonne/year)				
Sector	GMR		Hunter region	
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
Road Transport	2,793	2,071	350	264
Non-Road Equipment and Transport[1]	3,607	3,433	1,903	1,841
Natural Sources	33,638	7,338	2,338	1,044
Household Activities	8,189	7,873	1,073	1,032
EPA-Licensed Industry	73,213	17,672	56,654	11,723
Commercial Businesses	2,021	695	448	105
Grand Total	**123,461**	**39,083**	**62,766**	**16,009**

[1] Includes air transport, commercial boats, commercial non-road vehicles and equipment, industrial (EPA-licensed) non-road vehicles and equipment, rail transport, recreational boats and shipping. All commercial and industrial (EPA-licensed) non-road diesel vehicles and equipment assumed to have emissions control technology consistent be US Tier 0 and the sulfur content in diesel is 50 ppm.

In the GMR, commercial and industrial (EPA-licensed) non-road vehicles and equipment (diesel, gas and petrol) contribute 2% of PM_{10} and 5% of primary $PM_{2.5}$ emissions from all sources. Similarly, in the Hunter region commercial and industrial (EPA-licensed) non-road vehicles and equipment (diesel, gas and petrol) make-up 3% of primary PM_{10} and 11% of primary $PM_{2.5}$ emissions from all sources (EPA, 2012a).

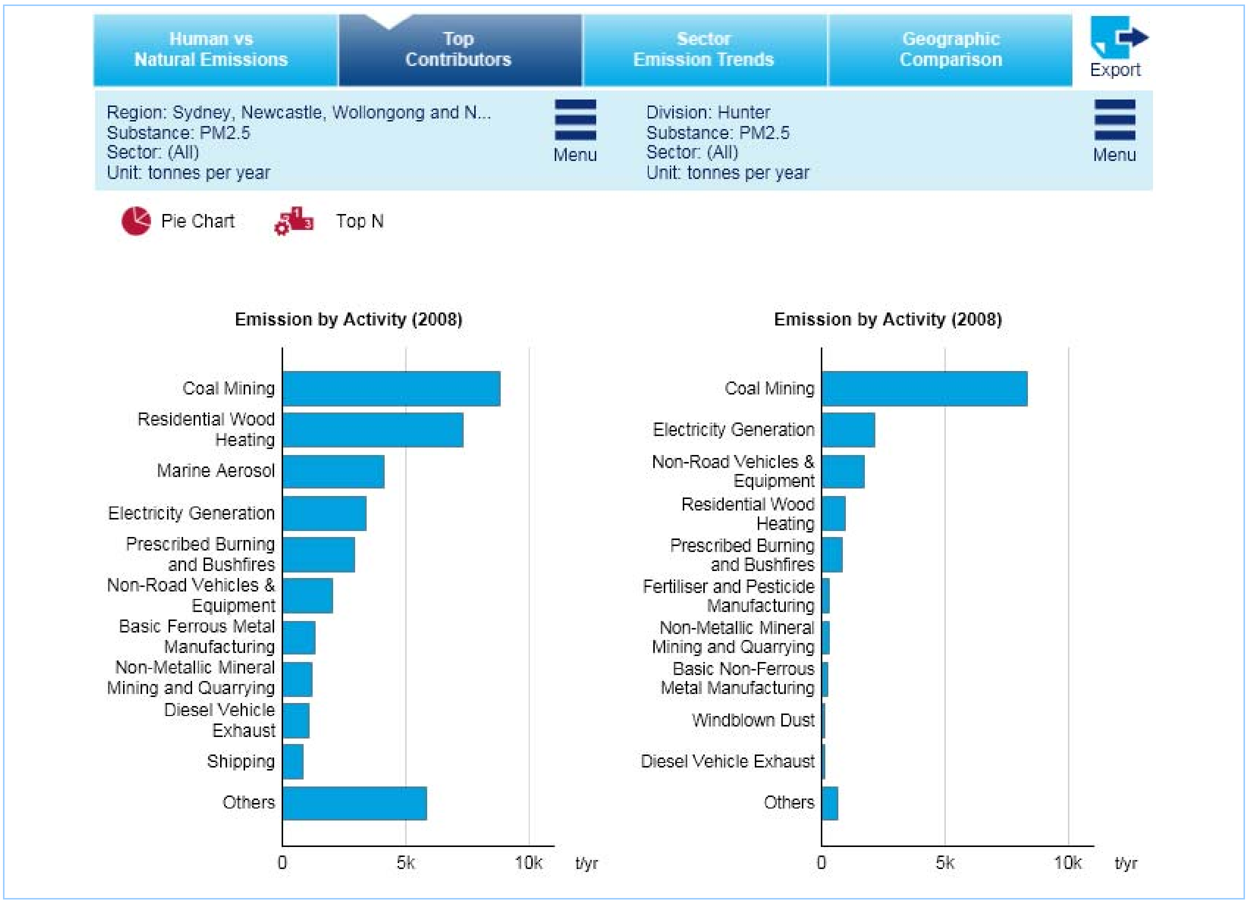
A comparison of the top 10 sources of primary PM_{10} and $PM_{2.5}$ emissions in the GMR and Hunter region is presented in Figure 3-4 and Figure 3-5. It should be noted the coal mining activity in Figure 3-4 and Figure 3-5 includes fugitive PM emissions only and does not include non-road diesels emissions.



Region: Sydney, Newcastle, Wollongong and N...
Substance: PM10
Sector: (All)
Unit: tonnes per year

Division: Hunter
Substance: PM10
Sector: (All)
Unit: tonnes per year

Figure 3-4: Top 10 sources of primary PM_{10} emissions in the GMR and Hunter region



Region: Sydney, Newcastle, Wollongong and N...
Substance: PM2.5
Sector: (All)
Unit: tonnes per year

Division: Hunter
Substance: PM2.5
Sector: (All)
Unit: tonnes per year

Figure 3-5: Top 10 sources of primary $PM_{2.5}$ emissions in the GMR and Hunter region

The top 10 sources of primary $PM_{2.5}$ emissions in the GMR and Hunter region by activity are presented in Table 3-2 and Table 3-3.

Table 3-2: Top 10 sources of primary $PM_{2.5}$ emissions in the GMR by activity

2008 calendar year in the GMR	
Activity	**$PM_{2.5}$ emissions (tonne/year)**
Coal Mining[1]	8,832
Residential Wood Heating	7,359
Marine Aerosol	4,114
Electricity Generation	3,422
Prescribed Burning and Bushfires	2,958
Non-Road Vehicles & Equipment[2]	2,042
Basic Ferrous Metal Manufacturing	1,351
Non-Metallic Mineral Mining and Quarrying	1,206
Diesel Vehicle Exhaust	1,115
Shipping	849
Others	5,835
Grand Total	**39,083**

[1] The coal mining activity includes fugitive PM emissions only and does not include non-road diesels emissions.
[2] All commercial and industrial (EPA-licensed) non-road diesel vehicles and equipment assumed to have emissions control technology consistent be US Tier 0 and the sulfur content in diesel is 50 ppm.

Table 3-3: Top 10 sources of primary $PM_{2.5}$ emissions in the Hunter region by activity

2008 calendar year in the Hunter region	
Activity	**$PM_{2.5}$ emissions (tonne/year)**
Coal Mining[1]	8,332
Electricity Generation	2,182
Non-Road Vehicles & Equipment[2]	1,747
Residential Wood Heating	972
Prescribed Burning and Bushfires	851
Fertiliser and Pesticide Manufacturing	355
Non-Metallic Mineral Mining and Quarrying	309
Basic Non-Ferrous Metal Manufacturing	265
Windblown Dust	159
Diesel Vehicle Exhaust	150
Others	687
Grand Total	**16,009**

[1] The coal mining activity includes fugitive PM emissions only and does not include non-road diesels emissions.
[2] All commercial and industrial (EPA-licensed) non-road diesel vehicles and equipment assumed to have emissions control technology consistent be US Tier 0 and the sulfur content in diesel is 50 ppm.

In terms of primary $PM_{2.5}$ emissions, commercial and industrial (EPA-licensed) non-road vehicles and equipment (diesel, gas and petrol) contribute 5% (natural & anthropogenic)/6% (anthropogenic) in the GMR and 11% (natural & anthropogenic)/12% (anthropogenic) in the Hunter region. Commercial and industrial (EPA-licensed) non-road vehicles and equipment (diesel, gas and petrol) are the sixth and third largest source of primary $PM_{2.5}$ emissions in the GMR and Hunter region, respectively. In the GMR, emissions of primary $PM_{2.5}$ from non-road diesels at coal mines have been estimated to be 1,754 tonne/year or 86% of all commercial and industrial (EPA-licensed) non-road vehicles and equipment (diesel, gas and petrol) emissions in the GMR. Similarly, in the Hunter region, emissions of primary $PM_{2.5}$ from non-road diesels at coal mines have been estimated to be 1,665 tonne/year or 95% of all commercial and industrial (EPA-licensed) non-road vehicles and equipment (diesel, gas and petrol) emissions in the Hunter region. Non-road diesels at coal mines are a significant source of primary $PM_{2.5}$ emissions in the GMR and the Hunter region.

When considering emissions from coal mines alone in the GMR, non-road diesels contribute 3% of primary PM_{10} (8th largest out of 54,271 tonne/year) and 17% of primary $PM_{2.5}$ (4th largest out of 10,586 tonne/year) emissions. A comparison of the major sources of primary PM_{10} and $PM_{2.5}$ emissions from coal mines in the GMR is presented in Figure 3-6.

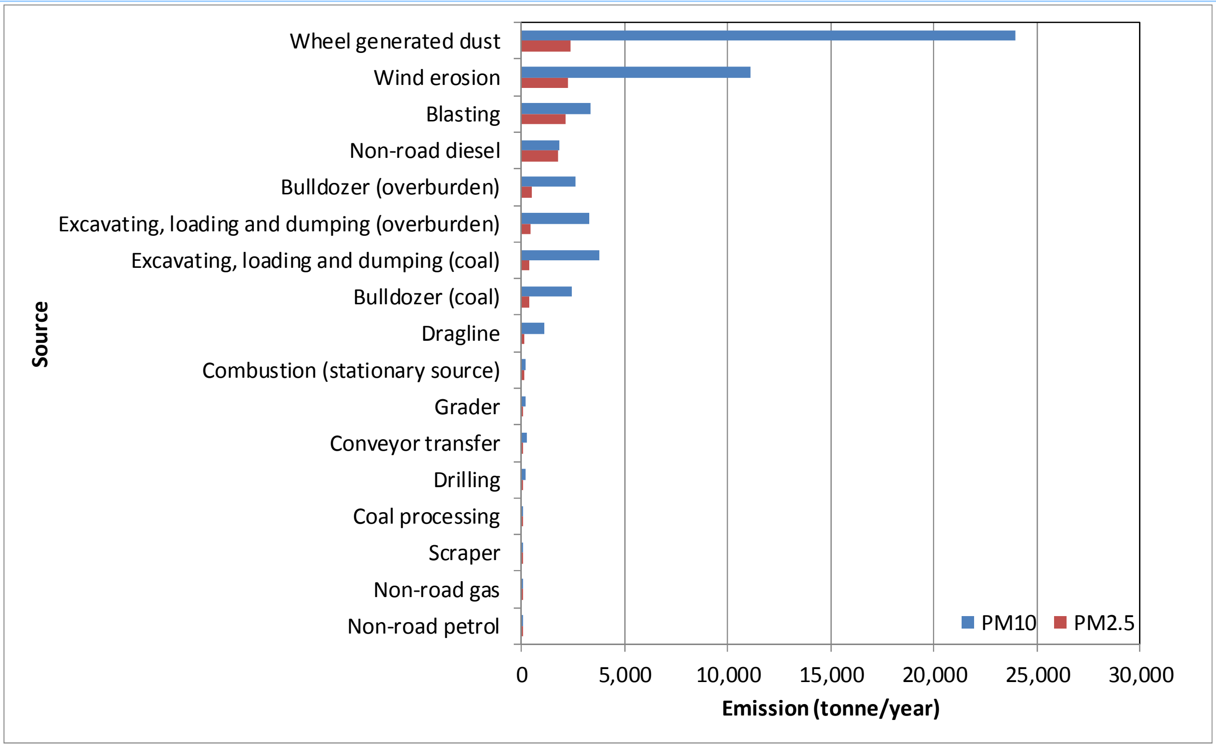


Figure 3-6: Top sources of primary PM_{10} and $PM_{2.5}$ emissions from coal mines in the GMR

3.2.2 National Pollutant Inventory

The *National Environment Protection (National Pollutant Inventory) Measure* (National Pollutant Inventory NEPM) (NEPC, 2008) establishes the NPI database (DSEWPC, 2013). The NPI database is a comprehensive repository of national information on pollutant emissions and waste transfers and is compiled in partnership with State and Territory governments. The NPI database contains annually updated information on emissions of 93 key pollutants to air, water and land as well as information on waste transfers from industrial facilities. It also includes information on pollution prevention initiatives undertaken by facilities.

A search of the NPI database has been done for emissions of primary $PM_{2.5}$ from facilities in NSW for the 2011/2012 financial year (DSEWPC, 2013). Primary $PM_{2.5}$ has been chosen, since only combustion sources are required to report emissions to air for this substance (DSEWPC, 2012). In the case of coal mining, combustion emissions are largely made up of non-road diesels, while coal seam gas combustion and blasting are less significant. NPI emissions of primary $PM_{2.5}$ from facilities in NSW for the 2011/2012 financial year are presented in Table 3-4 and shown in Figure 3-7. In relation to combustion related primary $PM_{2.5}$ emissions from facilities in NSW, coal mining is the largest source and contributes over 43% from all facilities.

Table 3-4: NPI emissions of primary $PM_{2.5}$ from facilities in NSW for the 2011/2012 financial year

ANZSIC Group	$PM_{2.5}$ emissions (kg/year)	Proportion (%)	Cumulative proportion (%)
Coal Mining [060]	2,476,297	43.4	43.4
Electricity Generation [261]	2,037,702	35.7	79.1
Sugar and Confectionery Manufacturing [118]	175,431	3.1	82.1
Metal Ore Mining [080]	149,252	2.6	84.8
Other Wood Product Manufacturing [149]	128,420	2.2	87.0
Basic Ferrous Metal Manufacturing [211]	118,506	2.1	89.1

ANZSIC Group	$PM_{2.5}$ emissions (kg/year)	Proportion (%)	Cumulative proportion (%)
Glass and Glass Product Manufacturing [201]	97,518	1.7	90.8
Log Sawmilling and Timber Dressing [141]	96,423	1.7	92.5
Meat and Meat Product Manufacturing [111]	76,320	1.3	93.8
Petroleum and Coal Product Manufacturing [170]	61,428	1.1	94.9
Basic Non-Ferrous Metal Manufacturing [213]	43,706	0.8	95.7
Other	247,930	4.3	100.0

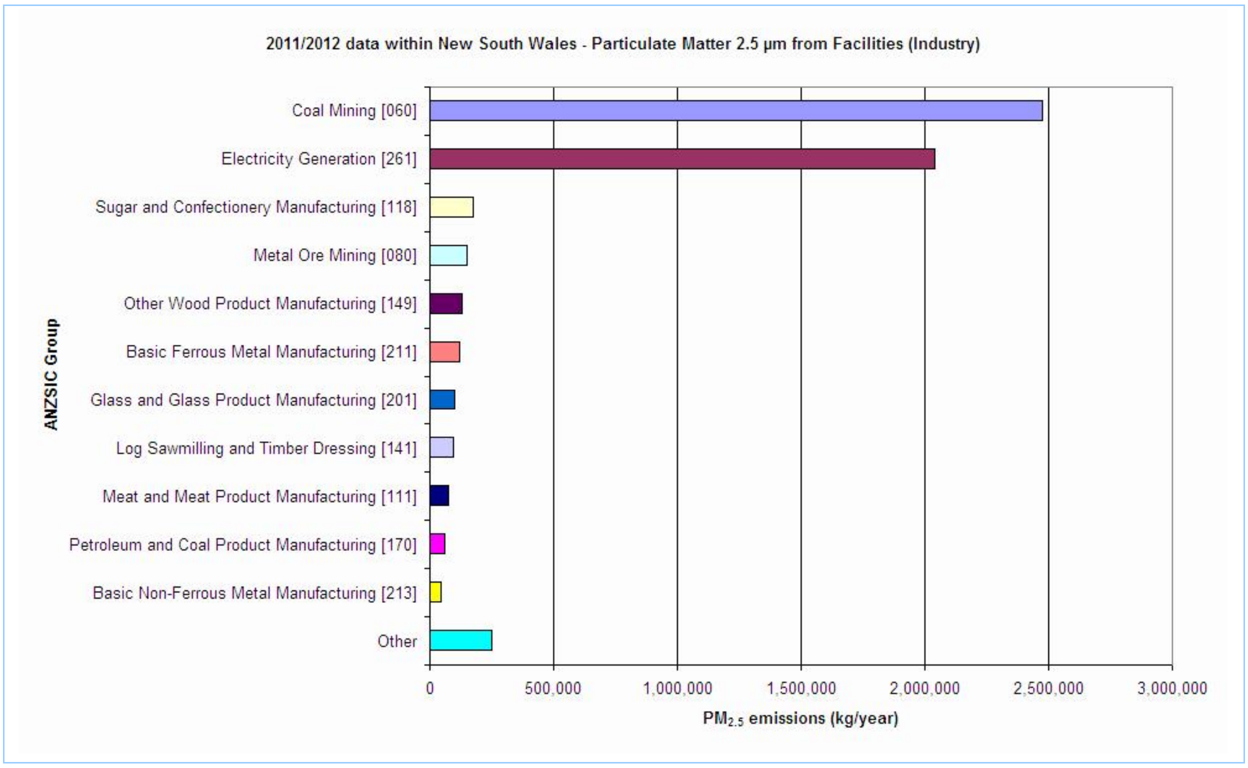


Figure 3-7: NPI emissions of primary $PM_{2.5}$ from facilities in NSW for the 2011/2012 financial year

3.3 Particle Composition Studies

This section provides a summary of the composition of PM in ambient air at communities situated close to coal mines.

3.3.1 *Upper Hunter Fine Particle Characterisation Study*

The *Upper Hunter Fine Particle Characterisation Study* (Hibberd et. al., 2013) determined the composition of particulate matter ($PM_{2.5}$) in ambient air sampled at the Upper Hunter Air Quality Monitoring Network (UHAQMN) sites in Singleton and Muswellbrook.

The components and sources that make-up ambient $PM_{2.5}$ are ranked as follows for:

Singleton

- secondary sulfate, 20 ± 2%
- industry aged sea salt, 18 ± 3%
- vehicle/industry, 17 ± 2%
- wood smoke, 14 ± 2%
- soil, 12 ± 2%
- biomass smoke, 8 ± 2%
- sea salt, 8 ± 1%
- secondary nitrate, 3 ± 2%.

Muswellbrook

- wood smoke, 30 ± 3%
- secondary sulfate, 17 ± 2%
- industry aged sea salt, 13 ± 2%
- biomass smoke, 12 ± 2%
- soil, 11 ± 1%
- vehicle/industry, 8 ± 1%
- secondary nitrate, 6 ± 1%
- sea salt, 3 ± 1%.

Figure 3-8 and Figure 3-9 show the annual and seasonal variations in the contributions from each component and source at Singleton and Muswellbrook, respectively. Wood smoke dominates at both sites during winter, while secondary sulfate and industry aged sea salt makes higher contributions during summer months. Vehicles/industry makes a significant contribution to the make-up of ambient $PM_{2.5}$ at both sites (17% Singleton and 8% Muswellbrook).

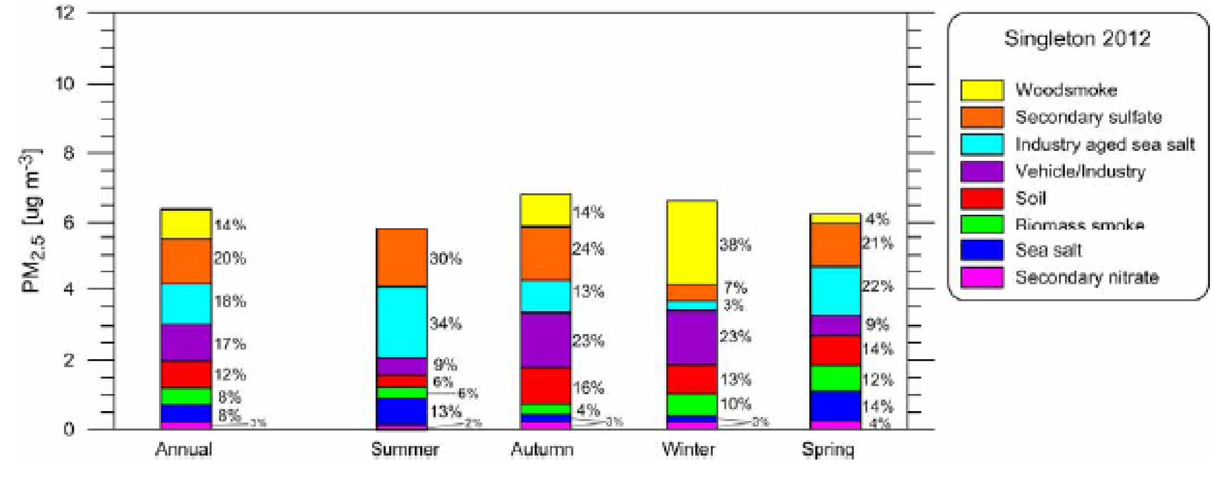


Figure 3-8: Annual and seasonal components and sources of annual average $PM_{2.5}$ in Singleton

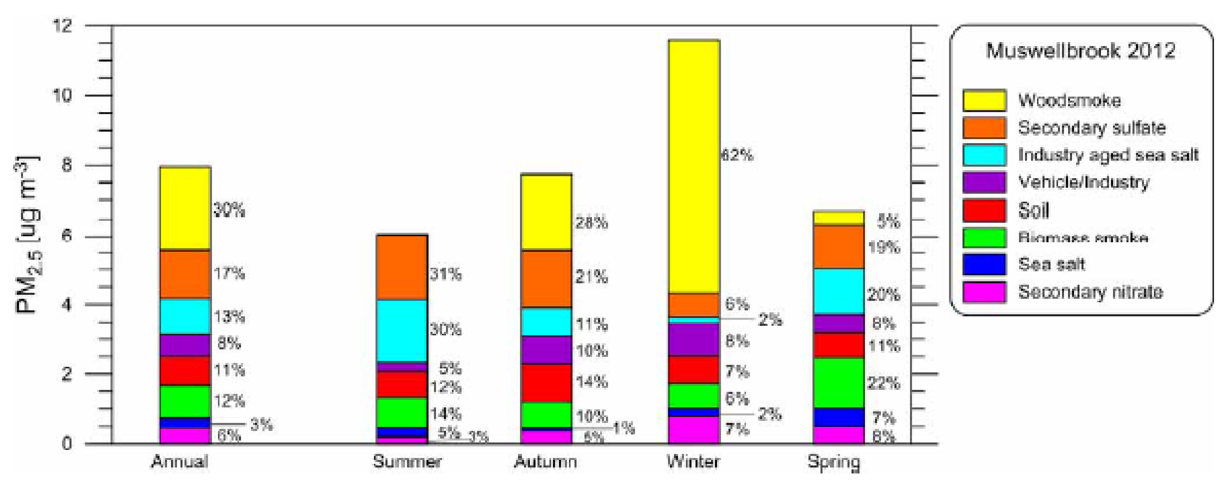


Figure 3-9: Annual and seasonal components and sources of annual average $PM_{2.5}$ in Muswellbrook

3.4 Reconciling Air Emissions Inventory & Particle Composition Data

When interpreting source pollution (Section 3.2) and particle composition (Section 3.3) data, it is important to understand the relationship between PM emissions and ambient concentrations is quite complex and influenced by a number of factors. How these emissions are dispersed, transported and transformed depends primarily on:

- **meteorology** (wind speed and direction, temperature, sunlight and rainfall) - high wind speeds tend to dilute emissions, while wind direction dictates where they are transported. Medium and long range transport of emissions may also impact on ambient concentrations when emissions from a large distant source are transported by wind. Temperature and sunlight play a key role in atmospheric reactions
- **topography** (surrounding terrain) - this can either trap emissions, influence how they disperse or determine the direction they are transported
- **atmospheric reactions** - in addition to primary emissions, secondary particulate matter, such as inorganic sulfates & nitrates and secondary organic aerosols (SOA)) can also be formed
- **source type** (either point or area) - the influence of a particular emission source on ambient concentrations tends to decrease with distance from the source. Substances may be emitted from a point source, like a boiler chimney, or over a wider area such as diffuse motor vehicle emissions in an urban road network.

While air emissions inventory data provides information on the key emission sources in a geographical area, it cannot be directly used to estimate ambient concentrations. Particle composition data provides the best estimate of the PM sources which influence ambient concentrations in those locations where ambient monitoring has been carried out.

4 AIR POLLUTION LEGISLATION IN NSW

This section summarises the air pollution legislation, which applies in NSW to all sources in general and coal mines, fuels and diesel non-road vehicles and equipment (non-road diesels) in particular.

4.1 Department of Sustainability, Environment, Water, Population and Communities

The Australian Government Department of Sustainability, Environment, Water, Population and Communities (DSEWPC) is responsible for developing nationally consistent policies, programs and legislation with respect to air quality and administering national fuel quality standards, both in its own right, and in partnership with the States and Territories. The DSEWPC website is located at http://www.environment.gov.au/.

4.1.1 Fuel Quality Standards Act 2000

The *Fuel Quality Standards Act 2000* (Attorney-General's Department, 2010) provides the legislative framework for setting national fuel quality and fuel quality information standards for Australia. The objects of the *Fuel Quality Standards Act 2000* are to provide information on fuel and to regulate the quality of fuel supplied in Australia in order to:

- Reduce the level of pollutants and emissions arising from the use of fuel that may cause environmental and health problems
- Facilitate the adoption of better engine technology and emission control technology
- Allow the more effective operation of engines
- Ensure that, where appropriate, information about fuel is provided when the fuel is supplied.

Where a State or Territory already has fuel quality standards in place, the Commonwealth standards supersede these unless the State or Territory standard is more stringent. State or Territory standards also apply where they regulate a fuel characteristic not covered by the Commonwealth standards.

The *Fuel Quality Standards Act 2000* allows fuel producers, suppliers and importers to apply for approval to supply a specified fuel that does not meet a given fuel standard but requires approval holders to report annually to the Department of Sustainability, Environment, Water, Population and Communities (DSEWPC) on the amount of such fuel produced and imported.

Fuel quality and fuel quality information standards have been made under the *Fuel Quality Standards Act 2000* for petrol, ethanol (E10 & E85), diesel, biodiesel and autogas. Fuel quality standards for diesel and biodiesel are directly relevant for this study as follows:

- **Diesel** – the *Fuel Standard (Automotive Diesel) Determination 2001* (Attorney-General's Department, 2009a) limits the: biodiesel content to 5% v/v (max from 1 March 2009); sulfur content to 10 ppm (max from 1 January 2009); cetane index to 46 (min from 1 January 2002); cetane number to 51 (min from 21 February 2009); and density 820 to 850 kg/m^3 (range from 1 January 2006)
- **Biodiesel** – the *Fuel Standard (Biodiesel) Determination 2003* (Attorney-General's Department, 2009b) limits the: sulfur content to 10 mg/kg (max from 1 February 2006); cetane number to 51 (min from 18 September 2005); and density 860 to 890 kg/m^3 (range from 18 September 2003).

4.2 Environment Protection Authority

The NSW Environment Protection Authority (EPA) is the State's lead environmental regulator. It is responsible for regulating a diverse range of activities that can have an impact on the health of the NSW environment and its people, including activities that result in air emissions. The NSW EPA also combines regulation with other tools, including education, partnerships and economic mechanisms. The NSW EPA website is located at http://www.epa.nsw.gov.au/.

4.2.1 Protection of the Environment (Operations) Act 1997

The *Protection of the Environment Operations Act 1997* (POEO Act) (PCO, 2010) is the principal piece of environmental legislation used in NSW to regulate air emissions. Using the POEO Act, the NSW EPA licenses scheduled industry activities, implements environmental regulatory requirements and conducts compliance and enforcement programs.

4.2.1.1 Best management practice

The *Protection of the Environment Operations Act 1997* (POEO Act) (PCO, 2010) provides the statutory framework for managing air emissions in NSW.

Reducing risks to human health through pollution prevention, cleaner production, reduction of pollution to harmless levels, application of the waste management hierarchy (i.e. reduction, re-use, recovery and recycling), continual environmental improvement and environmental monitoring are the broad objectives of the POEO Act (Chapter 1, Section 3).

Chapter 1 (Preliminary), Section 3 (Objects of Act) of the POEO Act specifically states:

3 Objects of Act

(d) to reduce risks to human health and prevent the degradation of the environment by the use of mechanisms that promote the following:
  - *(i) pollution prevention and cleaner production,*
  - *(ii) the reduction to harmless levels of the discharge of substances likely to cause harm to the environment,*
  - *(iia) the elimination of harmful wastes,*
  - *(iii) the reduction in the use of materials and the re-use, recovery or recycling of materials,*
  - *(iv) the making of progressive environmental improvements, including the reduction of pollution at source,*
  - *(v) the monitoring and reporting of environmental quality on a regular basis*

Air pollution related Sections 124 to 126 of the POEO Act require that operation of plant, maintenance work on plant and dealing with materials is done in a proper and efficient manner. Section 128 of the POEO Act requires that activities are carried out using those practicable means that may be required to prevent or minimise air pollution.

Part 5.4 (Air pollution), Division 1 General of the POEO Act specifically states:

124 Operation of plant (other than domestic plant)

The occupier of any premises who operates any plant in or on those premises in such a manner as to cause air pollution from those premises is guilty of an offence if the air pollution so caused, or any part of the air pollution so caused, is caused by the occupier's failure:
(a) to maintain the plant in an efficient condition, or
(b) to operate the plant in a proper and efficient manner.

125 Maintenance work on plant (other than domestic plant)

The occupier of any premises who carries out maintenance work on any plant in or on those premises in such a manner as to cause air pollution from those premises is guilty of an offence if the air pollution so caused, or any part of the air pollution so caused, is caused by the occupier's failure to carry out that work in a proper and efficient manner.

126 Dealing with materials

(1) The occupier of any premises who deals with materials in or on those premises in such a manner as to cause air pollution from those premises is guilty of an offence if the air pollution so caused, or any part of the air pollution so caused, is caused by the occupier's failure to deal with those materials in a proper and efficient manner.

(2) In this section:

deal with materials means process, handle, move, store or dispose of the materials.

materials includes raw materials, materials in the process of manufacture, manufactured materials, by-products or waste materials.

128 Standards of air impurities not to be exceeded

Where neither such a standard nor rate has been so prescribed, the occupier of any premises must carry on any activity, or operate any plant, in or on the premises by such practicable means as may be necessary to prevent or minimise air pollution.

Best management practice (BMP) is clearly the guiding principle in meeting the Objects and Air pollution requirements of the POEO Act. In defining BMP, consideration should be given to what are reasonable and feasible avoidance and mitigation measures. Taralga Landscape Guardians Inc. vs. Minister for Planning and RES Southern Cross Pty Ltd [2007] NSWLEC 59 (NSW LEC, 2007) defines reasonable and feasible as follows: *'Reasonable and Feasible Consideration of best practice taking into account the benefit of proposed measures and their technological and associated operational application in the NSW and Australian context. Feasible relates to engineering considerations and what is practical to build. Reasonable relates to the application of judgement in arriving at a decision, taking into account: mitigation benefits, cost of mitigation versus benefits provided, community views and the nature and extent of potential improvements'*.

4.2.1.2 Environment protection licences, notices and penalties

The POEO Act sets up a number of measures for pollution prevention and control, including:

- Environment protection licence (EPL) - activities listed in Schedule 1 to the POEO Act require an EPL. The EPA issues EPLs, which can control the air, noise, water and waste impacts of an activity. EPLs are on-going but subject to review at least once every five years and can be varied, suspended or revoked
- Pollution reduction program (PRP) - PRPs are legally enforceable programs that are negotiated with licensees and attached to EPLs. PRPs require changes to works or management practices to bring about environmental improvements within a specified timeframe
- Pollution incident response management plans and immediate notification of a pollution incident to all relevant authorities
- Environmental audits
- Economic measures, including load-based licensing
- Environment protection notices – these include clean up notices, prevention notices, prohibition notices, which may be directed to specific companies, individuals or public authorities
- Pollution as a criminal offence – there are three tiers of criminal offence with potential fines of up to $5 million for corporations or $1 million or up to seven years in jail for individuals.

While the EPA has powers to include EPL conditions aimed at preventing or minimising air pollution emissions from non-road diesels at coal mines, EPLs presently include generic requirements (EPA, 2013a). Environment protection licences for coal mines typically include Operating Conditions as follows:

4 Operating Conditions

O1 Activities must be carried out in a competent manner

O1.1 Licensed activities must be carried out in a competent manner.
This includes:
- *a) the processing, handling, movement and storage of materials and substances used to carry out the activity; and*
- *b) the treatment, storage, processing, reprocessing, transport and disposal of waste generated by the activity.*

O2 Maintenance of plant and equipment

O2.1 All plant and equipment installed at the premises or used in connection with the licensed activity:
- *a) must be maintained in a proper and efficient condition; and*
- *b) must be operated in a proper and efficient manner.*

O3 Dust

O3.1 The premises must be maintained in a condition which minimises or prevents the emission of dust from the premises.

O3.2 All trafficable areas, coal storage areas and vehicle manoeuvring areas in or on the premises must be maintained, at all times, in a condition that will minimise the generation, or emission from the premises, of wind-blown or traffic generated dust.

These Operating Conditions are essentially a reiteration of Part 5.4 (Air pollution), Division 1 General of the POEO Act. While BMP is the guiding principle of these operating conditions, the EPLs haven't traditionally included prescriptive requirements. However, the approach has now evolved through the *Dust Stop* program (EPA, 2011).

The *Dust Stop* program aims to ensure that the most reasonable and feasible PM control options are implemented by each coal mine. The *Dust Stop* program is being implemented through pollution reduction programs (PRP) attached to each coal mine EPL, which aim to reduce emissions of wheel generated dust and dust from handling overburden. The PRP typically include:

- Key performance indicator
- Monitoring method
- Location, frequency and duration of monitoring
- Record keeping
- Compliance reporting.

Copies of each coal mine EPL are available on the POEO Act public register (EPA, 2013a).

4.2.2 Protection of the Environment Operations (Clean Air) Regulation 2010

The POEO Act is supported by the *Protection of the Environment Operations (Clean Air) Regulation 2010* (POEO Clean Air Regulation) (PCO, 2011a), which provides regulatory measures to control emissions from domestic solid fuel heaters, open burning, motor vehicles and fuels, and commercial and industrial premises.

The POEO Clean Air Regulation supports the POEO Act by specifying requirements for air pollutants discharged from:

- **Part 2** - domestic solid fuel heaters
- **Part 3** - control of burning
- **Part 4** - motor vehicles and motor vehicle fuels
- **Part 5** - plant and activities
- **Part 6** - storage, transfer and distribution of volatile organic liquids.

Part 5 includes specifies standards of concentrations according to activities listed in Schedule 1 of the POEO Act. These standards of concentration are aimed at preventing or minimising air pollution from stationary sources but do not apply to non-road diesels and fugitive coal mine emissions.

4.2.3 Protection of the Environment Operations (General) Regulation 2009

The POEO Act is supported by the *Protection of the Environment Operations (General) Regulation 2009)* (POEO General Regulation) (PCO, 2013a), which establishes a load-based licensing (LBL) scheme for EPA-licensed premises and provides economic incentives for reducing emissions to air and water. The LBL scheme:

- sets clear minimum standards for environmental performance
- incorporates incentives for ongoing pollution reduction
- gives licensees flexibility to implement cost-effective pollution abatement methods
- increases regulatory transparency
- provides the infrastructure for emissions trading schemes
- enables the long-term tracking of emissions reductions.

Licence fees are made up of two components:

- Administrative fee
- Load-based fee.

The load-based fee is determined by the assessable pollutant, the amount emitted, the location of the activity and the season. Weighted factors are used to increase the fee payable for targeted pollutants in sensitive areas and seasons (e.g. oxides of nitrogen (NO_x) and volatile organic compound (VOC) emissions in Sydney during summer). The *Load Calculation Protocol* (DECC, 2009) sets out the methods that EPA-licensees must use to calculate annual assessable air and water pollutant loads. Non-road diesels and coal mines are not included in the LBL scheme.

4.3 Division of Resources and Energy

The Division of Resources and Energy (DRE) is part of NSW Trade & Investment (T&I). The DRE delivers policy, programs and compliance across the mining sector and is responsible for facilitating sustainable resource development, effective environmental management and safe and responsible mining in NSW. The DRE website is located at http://www.resources.nsw.gov.au/.

4.3.1 Coal Mine Health and Safety Act 2002

The aim of the *Coal Mine Health and Safety Act 2002* (CMHS Act) (PCO, 2013b) is to secure the health, safety and welfare of people in connection with the coal operation. The CMHS Act commenced on 23 December 2006 and requires that (NSW DPI, 2006a & 2006b):

- people with health and safety duties are clearly identified
- every coal operation must have a nominated person with the day-to-day control of the coal operation
- when more than one person has a responsibility, each discharges the responsibility in a co-ordinated manner
- an operator must have documented health and safety, emergency and major hazard management systems and plans in place
- an operator must ensure contractors work safely and follow a safe work method statement
- a contractor must provide a safe work method statement before starting work
- the Coal Competence Board will oversee health and safety competence in the coal mining industry
- employees have the right to elect check inspectors
- penalties for offences are provided.

The NSW Parliament passed the *Work Health and Safety (Mines) Act 2013* (WHS Act) (PCO, 2014) on 25 June 2013. The WHS Act was assented on 1 July 2013 but will not commence until the making of the supporting *Work Health and Safety (Mines) Regulation*. The WHS Act and Regulation will replace the CMHS Act and Regulation.

4.3.2 Coal Mine Health and Safety Regulation 2006

The object of the *Coal Mine Health and Safety Regulation 2006* (CMHS Regulation) (PCO, 2013c) is to prescribe certain matters for the purposes of the CMHS Act. In relation to non-road diesels, the CMHS Regulation requires that:

- Diesel engines, especially in underground coal mines, must be designed, operated and maintained in accordance with the Mechanical Engineering Management Plan (Part 2, Division 2, Subdivision 2, Clause 20)
- Diesel fuel must conform with Gazetted requirements (Part 4, Division 1, Subdivision 1 & Clause 73)
- Diesel engine exhausts must meet Gazetted emission limits and be regularly sampled and analysed (Part 4, Division 1, Subdivision 1 & Clause 74)
- Workplace exposure to diesel particulate matter (DPM) must be minimised as far as practicable (Part 4, Division 1, Subdivision 1 & Clause 75)
- Ability to Gazette specific requirements (such as design, certification, performance, assessment or installation requirements) for certain plant used at a coal operation (Part 4, Division 1, Subdivision 1 & Clause 76)
- For underground coal mines with diesel engines, the ventilation rate must be 0.06 m^3/s/kW or 3.5 m^3/s, whichever is greater (Part 4, Division 3, Subdivision 2, Clause 114).

4.3.3 Gazette Notices

This section summarises Gazette notices relating to the management of PM in general and coal mines, fuels and non-road diesels in particular, which have been issued under the *Coal Mine Health and Safety Act 2002* (CMHS Act) (PCO, 2013b) and *Coal Mine Health and Safety Regulation 2006* (CMHS Regulation) (PCO, 2013c).

4.3.3.1 Airborne Dust Limits, Collection and Analysis

The Gazette Notice *Airborne Dust Limits, Collection and Analysis* (PCO, 2007a) requires that:

- for underground mines with the exception of surface operations, the specified limits are 0.12 mg/m^3 and 2.5 mg/m^3 of respirable (~PM_5) quartz and respirable dust, respectively
- for open-cut mines, surface operations of underground mines and coal preparation plant, the specified limits are 0.1 mg/m^3 and 2.5 mg/m^3 of respirable (~PM_5) quartz and respirable (~PM_5) dust, respectively
- for all coal operations, the specified limit is 10 mg/m^3 for inhalable dust (~PM_{30})
- Sampling and analysis must be carried out in accordance with various Australian Standards for respirable and inhalable dust (Standards Australia, 2009a & 2009b) and NSW DPI requirements for respirable quartz (NSW DPI, 2008a).

4.3.3.2 Diesel Engine Exhaust

The Gazette Notice *Diesel Engine Exhaust* (PCO, 2007b) requires that:

- Mine atmosphere concentrations comply with carbon monoxide (CO), nitric oxide (NO) and nitrogen dioxide (NO_2) limits of 30, 25 and 3 ppm, respectively as a time weighted average (TWA). Compliance with a short term exposure limit (STEL) of 5 ppm for NO_2 also applies
- Diesel engine raw exhaust concentrations (measured prior to exhaust aftertreatment) comply with CO, oxides of nitrogen (NO_x) and NO_2 limits of 1,100, 750 and 100 ppm, respectively
- Sampling and analysis must be carried out by an accredited organization in accordance with the requirements of *Guideline for the Management of Diesel Engine Pollutants in Underground Environments* (MDG29) (NSW DPI, 2008b).

There are no specific requirements which apply to non-road diesels at open-cut coalmines.

4.3.3.3 Diesel Fuel Used Underground

The Gazette Notice *Diesel Fuel Used Underground* (PCO, 2011b) requires that:

- Diesel fuel must comply with the *Fuel Quality Standards Act 2000* (Attorney-General's Department, 2010), *Fuel Standard (Automotive Diesel) Determination 2001* (Attorney-General's Department, 2009a) and *Fuel Standard (Biodiesel) Determination 2003* (Attorney-General's Department, 2009b)
- Diesel fuel must not contain more than 10 mg/kg of sulfur
- Diesel fuel can comply with alternative requirements so long as an approved variation has been granted under the *Fuel Quality Standards Act 2000*.

Although there are no specific requirements which apply to non-road diesels at open-cut coalmines, the *Fuel Quality Standards Act 2000* requirements apply.

4.3.4 Guideline for the Management of Diesel Engine Pollutants in Underground Environments

The *Guidelines for the Management of Diesel Engine Pollutants in Underground Environments* (MDG29) (NSW DPI, 2008b) has been compiled to assist in formulating a systemic approach for the safe use of diesel engines in underground coal mines. The objective of the Guideline MDG29 is to minimise the risks to health and safety of workers exposed to diesel engine exhaust emissions when being used in underground coal mines.

To reduce worker exposure to diesel engine exhaust, the Guideline MDG29 (NSW DPI, 2008b) requires that:

- Mine atmosphere concentrations comply with carbon monoxide (CO), carbon dioxide (CO_2), nitric oxide (NO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), aldehyde and hydrocarbon workplace exposure limits, expressed as either a time weighted average (TWA) and/or a short term exposure limit (STEL) plus other relevant exposure limits published by Safe Work Australia (http://www.safeworkaustralia.gov.au/)
- Mine atmosphere concentrations comply with an elemental carbon (EC) concentration of 0.1 mg/m^3, which is approximately equal to 0.16 mg/m^3 of total carbon (TC) or 0.2 mg/m^3 of diesel particulate matter (DPM). Diesel particulate matter is made up of elemental carbon (EC), organic carbon (OC) and inorganic compounds (e.g. metals, non-metals, sulfates, nitrates etc.). Total carbon (TC) is made up of both EC and OC
- Diesel engine raw exhaust concentrations (measured prior to exhaust aftertreatment) comply with CO, oxides of nitrogen (NO_x) and NO_2 limits (refer to Section 4.3.3.2 for further details)
- Sampling and analysis must be carried out in accordance with various Australian Standards (http://www.standards.org.au/) and International Standards (http://www.iso.org/) for mine atmosphere and raw diesel engine exhaust concentrations.

There are no specific requirements which apply to non-road diesels at open-cut coalmines.

5 WORLDWIDE NON-ROAD DIESEL ENGINE EMISSION STANDARDS AND COSTS

This section provides a summary of worldwide emission standards and capital, maintenance and operating costs for diesel non-road vehicles and equipment (non-road diesels).

5.1 New Non-Road Diesel Engine Emission Standards

This section provides an overview of new worldwide emission standards for non-road diesels.

5.1.1 North America

This section provides an overview of new emission standards for non-road diesels in North America.

5.1.1.1 United States

Federal Emission Standards

Tier 1 regulations were the first United States (US) emission standards for non-road diesels and these were adopted by the US Environmental Protection Agency (EPA) in 1994 and phased in from 1996 to 2000. Stricter emission standards were stipulated in Tier 2 and Tier 3 regulations phased in from 2000 to 2008, followed by Tier 4 regulations phased in from 2008 to 2015 (Ecopoint Inc., 2013b & USEPA, 2012a).

US Tier 4 non-road diesel emission standards are approximately equivalent in stringency to heavy duty on-road diesel Euro 5 regulations (European Commission, 2014a) (adopted in Australian Design Rule (ADR), ADR80/03) (Attorney-General's Department, 2010) for particulate matter (PM) and Euro 6 regulations (European Commission, 2014a) (proposed as ADR80/04) (DIT, 2012) for oxides of nitrogen (NO_x).

Tier 1 to 3 non-road diesel emission standards are met through in-cylinder emissions control using advanced engine design with limited or no use of exhaust aftertreatment. Tier 4 emission standards require large reductions of NO_x and PM that can be achieved with advanced aftertreatment systems such as selective catalytic reduction (SCR) for NO_x control and diesel particulate filters (DPF) for PM control (Ecopoint Inc., 2013b & USEPA, 2013a).

The non-road diesel emission standards apply to mobile non-road engines of all sizes used in a wide range of construction, agricultural and industrial vehicles and equipment applications. The US definition of a non-road engine is based on the principle of mobility/portability (Ecopoint Inc., 2013b & USEPA, 2013a), and includes engines installed in:

- self-propelled equipment
- equipment that is propelled while performing its function, or
- equipment that is portable or transportable, as indicated by the presence of wheels, skids, carrying handles, dolly, trailer, or platform.

Non-road diesels subject to US regulation are all internal combustion compression ignition (CI) engines except:

- motor vehicle (highway) engines
- stationary engines (or engines that remain at one location for more than 12 months)
- engines used solely for competition, or
- engines used in aircraft.

Diesel engines used in railway locomotives and marine vessels above 37 kW are subject to separate US regulations, while diesel engines used in underground mines are subject to separate regulations (Ecopoint Inc., 2013b & USEPA, 2013a) administered by the US Mine Safety and Health Administration (MHSA) (http://www.msha.gov/).

Table 5-1 lists the Tier 1 to Tier 3 emission standards, Table 5-2 lists the Tier 4 emission standards for engines less than 560 kW, and Table 5-3 lists the emission standards for engines greater than or equal to 560 kW. The Tier 4 emission standards are phased in two stages (Ecopoint Inc., 2013b & USEPA, 2012a), where the:

- initial requirements are referred to as Tier 4 interim (Tier 4i), or Tier 4 transitional, while
- final requirements are referred to as Tier 4 final (Tier 4f).

In addition to the US emission standards presented in Table 5-1, Table 5-2 and Table 5-3, all Tier 1 to Tier 4 engines (with the exception of Tier 4 engines certified to PM emission standards at or below 0.07 g/kWh because an engine with such low PM levels has inherently low smoke emission) are required to meet smoke opacity limits of 20/15/50% at acceleration/lug/peak modes of the US smoke test procedure. Other provisions of the US non-road emission standards include emissions averaging, banking and trading of emission credits and maximum "family emission limits" for emission averaging.

Table 5-1: US Tier 1 – Tier 3 non-road diesel emission standards

Engine Power	Tier	Year	CO (g/kW.hr)	HC (g/kW.hr)	NMHC+NO$_x$ (g/kW.hr)	NO$_x$ (g/kW.hr)	PM (g/kW.hr)
< 8 kW	Tier 1	2000	8.0	-	10.5	-	1.0
	Tier 2	2005	8.0	-	7.5	-	0.80
8 ≤ kW < 19	Tier 1	2000	6.6	-	9.5	-	0.80
	Tier 2	2005	6.6	-	7.5	-	0.80
19 ≤ kW < 37	Tier 1	1999	5.5	-	9.5	-	0.80
	Tier 2	2004	5.5	-	7.5	-	0.60
37 ≤ kW < 75	Tier 1	1998	-	-	-	9.2	-
	Tier 2	2004	5.0	-	7.5	-	0.40
	Tier 3†	2008	5.0	-	4.7	-	0.40
75 ≤ kW < 130	Tier 1	1997	-	-	-	9.2	-
	Tier 2	2003	5.0	-	6.6	-	0.30
	Tier 3	2007	5.0	-	4.0	-	0.30
130 ≤ kW < 225	Tier 1	1996	11.4	1.3	-	9.2	0.54
	Tier 2	2003	3.5	-	6.6	-	0.20
	Tier 3	2006	3.5	-	4.0	-	0.20
225 ≤ kW < 450	Tier 1	1996	11.4	1.3	-	9.2	0.54
	Tier 2	2001	3.5	-	6.4	-	0.20

Engine Power	Tier	Year	CO (g/kW.hr)	HC (g/kW.hr)	NMHC+NO_x (g/kW.hr)	NO_x (g/kW.hr)	PM (g/kW.hr)
	Tier 3	2006	3.5	-	4.0	-	0.20
450 ≤ kW < 560	Tier 1	1996	11.4	1.3	-	9.2	0.54
	Tier 2	2002	3.5	-	6.4	-	0.20
	Tier 3	2006	3.5	-	4.0	-	0.20
≥ 560 kW	Tier 1	2000	11.4	1.3	-	9.2	0.54
	Tier 2	2006	3.5	-	6.4	-	0.20

[†]US Tier 3 standards apply to 37 ≤ kW < 560 only

Table 5-2: US Tier 4 non-road diesel emission standards < 560 kW

Engine Power	Year	CO (g/kW.hr)	NMHC (g/kW.hr)	NMHC+NO_x (g/kW.hr)	NOx (g/kW.hr)	PM (g/kW.hr)
< 8 kW	2008	8.0	-	7.5	-	0.40[a]
8 ≤ kW < 19	2008	6.6	-	7.5	-	0.40
19 ≤ kW < 37	2008	5.5	-	7.5	-	0.30
	2013	5.5	-	4.7	-	0.03
37 ≤ kW < 56	2008	5.0	-	4.7		0.30 [b]
	2013	5.0	-	4.7		0.03
56 ≤ kW < 130	2012 -2014[c]	5.0	0.19	-	0.40	0.02
130 ≤ kW < 560	2012 -2014[d]	3.5	0.19	-	0.40	0.02

[a]hand-startable, air-cooled, DI engines may be certified to US 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; NOx+HC dependent on Tier 2 credits, full compliance from 31/12/2014
[d]PM & CO: full compliance from 2011; NOx+HC 50% of engines must comply 2011-2013

Table 5-3: US Tier 4 non-road diesel emission standards engines ≥ 560 kW

Year	Application	CO (g/kW.hr)	NMHC (g/kW.hr)	NO_x (g/kW.hr)	PM (g/kW.hr)
2011	Generator sets > 900 kW	3.5	0.4	0.67	0.10
	All other engines	3.5	0.4	3.5	0.10
2015	Generator sets	5.0	0.19	0.67	0.03
	All other engines	5.0	0.19	3.5	0.04

Transition Program for Equipment Manufacturers

The US federal emission standards for non-road diesels include flexibility provisions, which are known as the Transitional Program for Equipment Manufacturers (TPEM). The TPEM allows equipment manufacturers to produce limited numbers of equipment with engines that meet previous tiers of less stringent emission standards after a new tier of emission standards comes into effect (Ecopoint Inc., 2013b & USEPA, 2012a).

In relation to Tier 4 engines, the TPEM allows equipment manufacturers to install a limited number of exempted engines during a seven year period after the Tier 4 effective dates. The TPEM flexibility is available during the time periods shown in Table 5-4 (Ecopoint Inc., 2013b).

Table 5-4: US Tier 4 availability for TPEM allowances

Engine Power	General Availability	Delayed Availability
< 19 kW	2008-2014	2012-2018
19 ≤ kW < 56	2008-2014	2014-2020
56 ≤ kW < 130	2012-2018	2014-2020
130 ≤ kW < 560	2011-2017	2014-2020
≥ 560 kW	2011-2017	2015-2021

Manufacturers must choose either the general availability period or the delayed availability period options, although these two options may not be combined. For the general availability period option, manufacturers are able to supply Tier 3 engines after the Tier 4i emission standards are required but Tier 4f engines must be supplied at the end of the general availability period. Similarly, for the delayed availability period option, a manufacturer must supply Tier 4i engines after both the Tier 4i and Tier 4f emission standards are required but must supply Tier 4f engines at the end of the delayed availability period.

The numbers of engines that may be exempted under the TPEM is determined by one of two options:

- **Percentage of Production** - The percentage of exempted engines sold within a power category relative to the manufacturer's total US market sales of engines in the power category is calculated per year over the seven year flexibility period. The total of percentages summed over the period may not exceed 80%. For example a manufacturer may exempt 25% of engines in year 1, 20% in year 2, 15% in year 3 and 10% in years 4 and 5 to use their allowed exemptions
- **Small volume allowances** - A manufacturer may choose one of the following approaches:
  - A manufacturer may exempt up to 700 engines within a power category over the seven year flexibility period with no more than 200 engines in any one year. Engines exempt under this clause in any one year must all be from a single engine family
  - For engines < 130 kW, a manufacturer may exempt up to 525 engines within a power category during the seven year flexibility period, with no more than 150 engines in any single year within a power category. For engines ≥ 130 kW, up to 350 engines within a power category during the seven year flexibility period, with no more than 100 engines in any single year within a power category. Exemptions may apply to engines from multiple engine families in a given year.

Diesel Fuel Sulfur Standards

Prior to June 2007, the sulfur content in US non-road diesel fuels was not subject to regulation, with average in-use levels of around 0.3% or 3000 ppm. Sulfur content limits were phased in to allow for the use of sulfur sensitive emission control technologies, primarily exhaust aftertreatment equipment including diesel oxidation catalysts (DOC) and diesel particulate filters (DPF) and to reduce PM emissions. The following sulfur content limits apply in the US for non-road, locomotive and marine diesel fuels (USEPA, 2012b):

- 500 ppm from June 2007 for non-road, locomotive and marine diesel fuels
- 15 ppm from June 2010 for non-road and June 2012 for locomotive and marine diesel fuels.

5.1.1.2 Canada

Canada promulgated the *Off-Road Compression-Ignition Engine Emission Regulations (SOR/2005-32)* on February 23, 2005 adopting US Tier 2 and Tier 3 standards starting in 2006. In 2000, Canada signed a memorandum of understanding with 13 engine manufacturers requiring them to supply engines meeting US Tier 1 emission standards until the Tier 2 emissions standards came into effect (Ecopoint Inc., 2013c & Environment Canada, 2012).

The regulations apply to all diesel engines with the following exemptions:

- Engines used exclusively for competition
- Engines regulated by *the On-Road Vehicle and Engine Emission Regulations (SOR/2003-2)* (http://www.ec.gc.ca/lcpe-cepa/eng/regulations/detailReg.cfm?intReg=65)
- Engines used exclusively in underground mines
- Engines with a per-cylinder displacement of less than 50 cm^3
- Engines for military machines used in combat or combat support
- Engines being exported and not sold or used in Canada
- Engines in a marine vessel and for which the fuel, cooling and exhaust systems are integral parts of the marine vessel
- Locomotives.

The Canada non-road diesel engine emission regulations do not include the averaging, banking and trading clauses that are part of the US federal emission standards for non-road diesels. The Canada Tier 2 and 3 emission standards are presented in Table 5-5 (Ecopoint Inc., 2013c & Environment Canada, 2012).

Table 5-5: Canada Tier 2 – Tier 3 non-road diesel emission standards

Engine Power	Tier	Year	CO (g/kW.hr)	$NMHC+NO_x$ (g/kW.hr)	PM (g/kW.hr)
< 8 kW	Tier 2	2006	8.0	7.5	0.80
8 ≤ kW < 19	Tier 2	2006	6.6	7.5	0.80
19 ≤ kW < 37	Tier 2	2006	5.5	7.5	0.60
37 ≤ kW < 75	Tier 2	2006	5.0	7.5	0.40
	Tier 3	2008	5.0	4.7	0.40
75 ≤ kW < 130	Tier 2	2006	5.0	6.6	0.30
	Tier 3	2007	5.0	4.0	0.30
130 ≤ kW < 225	Tier 3	2006	3.5	4.0	0.20
225 ≤ kW < 450	Tier 3	2006	3.5	4.0	0.20
450 ≤ kW < 560	Tier 3	2006	3.5	4.0	0.20
≥ 560 kW	Tier 2	2006	3.5	6.4	0.20

Canada implemented Tier 4 emission standards in January 2012 to align them with the US Tier 4 emission standards. The US Transitional Program for Equipment Manufacturers (TPEM) has been adopted so that manufacturers can supply a certain number of Tier 3 engines for up to four years after the start date of the Tier 4 emission standards, or alternatively, extend the supply of Tier 4 interim engines past the start date of the Tier 4 final compliance data by up to six years.

5.1.2 Europe

This section provides an overview of new emission standards for non-road diesels in Europe.

5.1.2.1 European Union

The European Union (EU) emission standards for non-road diesels adopt similar regulations to the US Tier 1 to 4 emission standards, referred to by the EU as Stage I to Stage IV (Ecopoint Inc., 2013d & European Commission, 2013). Stage I and Stage II emission standards were promulgated in 1997 and introduced in 1999 and 2001-2004, respectively. The emission standards apply to industrial drilling rigs, compressors, construction wheel loaders, bulldozers, non-road trucks, highway excavators, forklift trucks, road maintenance equipment, snow ploughs, ground-support equipment in airports, aerial lifts and mobile cranes. Agricultural and forestry tractors have the same emission standards but different implementation dates. Engines used in ships, railway locomotives, aircraft, and generating sets are not covered by the Stage I and Stage II emission standards. Engines greater than 560 kW are not covered by the emission standards (Ecopoint Inc., 2013d & European Commission, 2013).

Stage III and Stage IV emission standards were promulgated in 2004. Stage III emission standards were introduced in two steps, Stage IIIA and Stage IIIB (phased in from 2006 to 2013), while Stage IV emission standards were introduced in 2014. Stage III and IV also introduced emission standards for locomotives and marine vessels used on inland waterways (Ecopoint Inc., 2013d & European Commission, 2013).

On 25 September 2014, the EU proposed Stage V emission standards (Ecopoint Inc. 2014 & European Commission, 2014). The proposed emission standards will:

- Extend the emission standards to engines above 560 kW and engines below 19 kW
- Include some previously unregulated engine categories
- Reduce the PM limit from 0.025 to 0.015 g/kW.hr for engines from 19-560 kW and introduce a standard of 0.045 g/kW.hr for engines above 560 kW
- Include a particle number (PN) limit of $1x10^{-12}$/kW.hr for engines from 19-560 kW which will force the use of diesel particulate filters
- Include provisions for in-service testing.

With regard to the engines above 560 kW which are most relevant for open cut coal mining operations, the Stage V standards are proposed to apply from 2018/2019.

The EU Stage I and Stage II emission standards are presented in Table 5-6, EU Stage IIIA emission standards in Table 5-7 and EU Stage IIIB and Stage IV emission standards in Table 5-8 (Ecopoint Inc., 2013d & European Commission, 2013).

Table 5-6: European Union Stage I – Stage II non-road diesel emission standards

Category	Engine Power	Date	CO (g/kW.hr)	HC (g/kW.hr)	NOx (g/kW.hr)	PM (g/kW.hr)
Stage I						
A	130 ≤ kW < 560	Jan 1999	5.0	1.3	9.2	0.54
B	75 ≤ kW < 130	Jan 1999	5.0	1.3	9.2	0.70
C	37 ≤ kW < 75	Apr 1999	6.5	1.3	9.2	0.85
Stage II						
E	130 ≤ kW < 560	Jan 2002	3.5	1.0	6.0	0.20
F	75 ≤ kW < 130	Jan 2003	5.0	1.0	6.0	0.30
G	37 ≤ kW < 75	Jan 2004	5.0	1.3	7.0	0.40
D	18 ≤ kW < 37	Jan 2001	5.5	1.5	8.0	0.80

Table 5-7: European Union Stage IIIA non-road diesel emission standards

Category	Engine Power	Date	CO (g/kW.hr)	$HC+NO_x$ (g/kW.hr)	PM (g/kW.hr)
H	130 ≤ kW < 560	Jan 2006	3.5	4.0	0.20
I	75 ≤ kW < 130	Jan 2007	5.0	4.0	0.30
J	37 ≤ kW < 75	Jan 2008	5.0	4.7	0.40
K	19 ≤ kW < 37	Jan 2007	5.5	7.5	0.60

Table 5-8: European Union Stage IIIB – Stage IV non-road diesel emission standards

Category	Engine Power	Date	CO (g/kW.hr)	HC (g/kW.hr)	NOx (g/kW.hr)	PM (g/kW.hr)
L	130 ≤ kW < 560	Jan 2011	3.5	0.19	2.0	0.025
M	75 ≤ kW < 130	Jan 2012	5.0	0.19	3.3	0.025
N	56 ≤ kW < 75	Jan 2012	5.0	0.19	3.3	0.025
P	37 ≤ kW < 56	Jan 2013	5.0	4.7 ($HC+NO_x$)		0.025
Stage IV						
Q	130 ≤ kW < 560	Jan 2014	3.5	0.19	0.4	0.025
R	56 ≤ kW < 130	Oct 2014	5.0	0.19	0.4	0.025

5.1.2.2 Germany

Emission standards for non-road diesels in Germany are fully harmonised with the European Union. However, Germany prescribes exposure limits in the workplace and engine emission standards in order to minimise occupational exposure to diesel exhaust emissions (Ecopoint Inc., 2013e).

There are two types of exposure limits:

- MAK (Maximale Arbeitsplatzkonzentration) is the maximum concentration of a substance in the ambient air in the workplace which has no adverse effect on the workers' health
- TRK (Technische Richtkonzentration) is the concentration of a substance in the ambient air in the workplace that can be achieved using technically available measures.

Table 5-9 lists the Germany exposure limits for diesel exhaust pollutants from *Technische Regeln für Gefahrstoffe 900* or *Technical Rules for Hazardous Substances 900* (http://www.baua.de/de/Themen-von-A-Z/Gefahrstoffe/TRGS/TRGS-900.html) (Ecopoint Inc., 2013e).

Table 5-9: Germany exposure limits for diesel exhaust pollutants

Substance	ppmv	mg/m^3	Category*
CO	30	33	4
CO_2	5000	9000	4
NO	25	30	-
NO_2	5	9	1
HCHO	0.5	0.6	1
SO_2	2	5	1
Diesel Particulates (EC)[a], tunnelling & non-coal mining	-	0.3[b]	4
Diesel Particulates (EC)[a], other applications	-	0.1[b]	-

*All values in the table have to be met as work-shift time weighted averages. The following short term exposure categories apply: 1 - ceiling value, not to be exceeded at any point in time; 4 - ceiling value = 4 x the limit value

[a] Elemental carbon

[b] TRK limit. Coal mines are exempted from these limits due to the difficulties in differentiating between diesel particulates and coal dust

The *Technische Regel für Gefahrstoffe 554* or *Technical Rules for Hazardous Substances 554* (http://www.baua.de/de/Themen-von-A-Z/Gefahrstoffe/TRGS/TRGS-554.html) prescribes additional requirements whenever diesel engines are operated in buildings, underground, or other enclosed areas, including coal mines, including (Ecopoint Inc., 2013e):

- Diesel engines that are entirely or partially operated in enclosed spaces or underground must be equipped with particulate traps, provided such traps are technically feasible
- The particulate traps must achieve at least 70% total gravimetric filtration rate, as measured on the UBA (*Umwelt Bundesamt*) engine test cycle
- Diesel engines must undergo periodic measurements of smoke number and CO.

5.1.2.3 Russia

Russia has adopted Stage I and Stage III European Union emission standards for non-road diesels and these are presented in Table 5-10 (Ecopoint Inc., 2013f).

Table 5-10: Russia non-road diesel emission standards

Date	Standard	EU Equivalent
2000	GOST R41 96-99	Stage I
2014	GOST R41 96-2011	Stage III

5.1.2.4 Sweden

Emission standards for non-road diesels in Sweden are fully harmonised with the European Union.

5.1.2.5 Switzerland

Emission standards for non-road diesels in Switzerland are fully harmonised with the European Union. Switzerland also prescribes exposure limits in the workplace in order to minimise occupational exposure to diesel exhaust emissions and these are known as MAK (Maximale Arbeitsplatzkonzentration) or the maximum concentration of a substance in the ambient air in the workplace which has no adverse effect on the workers' health (Ecopoint Inc., 2013h).

Table 5-11 lists the Switzerland exposure limits for diesel exhaust pollutants from *Grenzwerte am Arbeitsplatz 2001* or *Limit in the Workplace 2001* (Ecopoint Inc., 2013h).

Table 5-11: Switzerland exposure limits for diesel exhaust pollutants

Substance	Exposure limit
CO	30 ppm
CO_2	5000 ppm
NO	25 ppm
NO_2	3 ppm
SO_2	1.3 mg/m^3
Diesel particulates	0.1 mg/m^3 (EC)[a]
[a]Elemental carbon	

5.1.2.6 Turkey

Turkey has adopted the European Union emission standards for non-road diesel with varied implementation dates and these are presented in Table 5-12 (Ecopoint Inc., 2013i).

Table 5-12: Turkey non-road diesel emission standards

Stage	Engine Power	Date
Mobile Non-road engines		
Stage I	37 ≤ kW ≤ 560	Apr 2003
Stage II	18 ≤ kW ≤ 560	2007
Stage IIIA	19 ≤ kW ≤ 560	2010
Stage IIIB	130 ≤ kW ≤ 560	2011
	56 ≤ kW < 130	2012
	37 ≤ kW < 56	2013
Stage IV	130 ≤ kW ≤ 560	2014
	56 ≤ kW < 130	Oct 2014

5.1.3 Asia

This section provides an overview of new emission standards for non-road diesels in Asia.

5.1.3.1 Japan

Non-road diesels are regulated in Japan in two equipment classes (Ecopoint Inc., 2013j & Ecopoint Inc., 2013k):

- Special motor vehicles are non-road vehicles registered for use on public roads, such as forklifts, agricultural tractors and wheel loaders
- Construction machinery such as backhoe loaders, tractor-type loaders, concrete sprayers, drills, dump trucks, truck mixers, generators, air compressors and wheel cranes.

Emission standards for special motor vehicles were introduced in 2003, which are equivalent to US Tier 2/EU Stage II and are commonly referred to as the MOT (Ministry or Transport) standards. Stage 1 emission standards for construction machinery were introduced in 1996, which are equivalent to US Tier 1/EU Stage I, while Stage 2 emission standards were introduced in 2003 along with the special motor vehicle standards. The construction machinery standards are commonly referred to as the MOC (Ministry of Construction) standards (Ecopoint Inc., 2013k).

The Japan MOT emission standards are presented in Table 5-13, while the Stage 1 and Stage 2 Japan MOC emission standards are presented in Table 5-14 (Ecopoint Inc., 2013k).

Table 5-13: Japan MOT non-road diesel emission standards for special motor vehicles

Engine Power	Date	CO (g/kW.hr)	HC (g/kW.hr)	NOx (g/kW.hr)	PM (g/kW.hr)
19 ≤ kW < 37	Oct 2003	5.0	1.5	8.0	0.80
37 ≤ kW < 75		5.0	1.3	7.0	0.40
75 ≤ kW < 130		5.0	1.0	6.0	0.30
130 ≤ kW < 560		3.5	1.0	6.0	0.20

Table 5-14: Japan MOC non-road diesel emission standards for construction machinery

Engine Power	Date	CO (g/kW.hr)	HC (g/kW.hr)	NOx (g/kW.hr)	PM (g/kW.hr)
Stage 1					
7.5 ≤ kW < 15	Apr 1996[a] Apr 1997[b] Apr 1998[c]	5.7	1.5	8.0	0.80
15 ≤ kW < 30		5.7	1.3	7.0	0.40
30 ≤ kW < 260		5.0	1.0	6.0	0.30
Stage 2					
8 ≤ kW < 19	Oct 2003	5.0	1.5	9.0	0.80
19 ≤ kW < 37		5.0	1.5	8.0	0.80
37 ≤ kW < 75		5.0	1.3	7.0	0.40
75 ≤ kW < 130		5.0	1.0	6.0	0.30

[a] applies to tunnel construction, [b] general construction - backhoes, tractor type loaders & bulldozers, [c] general construction – all other machines

Due to a government reorganisation the responsibility for the MOT and MOC emission standards passed to the Ministry of Land, Infrastructure & Transport (MLIT) and the Ministry of the Environment (MOE), respectively. The equipment definitions in the new emission standards were amended to add self-propelled to the description. The new emission standards are equivalent to US Tier 3/EU Stage IIIA emission standards from 2008-2010 and US Tier 4i/EU Stage IIIB emission standards from 2011-2016 (Ecopoint Inc., 2013j).

The Japan Stage 3 MLIT/MOE emission standards are presented in Table 5-15, while the Stage 4 MLIT/MOE emission standards are presented in Table 5-16 (Ecopoint Inc., 2013j).

Table 5-15: Japan 2006-2008 MLIT/MOE non-road diesel emission standards for special and non-road equipment

Engine Power	Date		CO (g/kW.hr)	HC (g/kW.hr)	NOx (g/kW.hr)	PM (g/kW.hr)
	New Models	All Models				
19 ≤ kW < 37	Oct 2007	Sep 2008	5.0	1.0	6.0	0.40
37 ≤ kW < 56	Oct 2008	Sep 2009	5.0	0.7	4.0	0.30
56 ≤ kW < 75	Oct 2008	Sep 2010	5.0	0.7	4.0	0.25
75 ≤ kW < 130	Oct 2007	Sep 2008	5.0	0.4	3.6	0.20
130 ≤ kW < 560	Oct 2006	Sep 2007	3.5	0.4	3.6	0.17

Table 5-16: Japan 2011-2016 MLIT/MOE non-road diesel emission standards for special and non-road equipment

Engine Power	Date		CO (g/kW.hr)	HC (g/kW.hr)	NOx (g/kW.hr)	PM (g/kW.hr)
	New Models	All Models				
19 ≤ kW < 37	Oct 2013	Sep 2015	5.0	0.7	4.0	0.03
37 ≤ kW < 56	Oct 2013	Nov 2014	5.0	0.7	4.0	0.025
56 ≤ kW < 75	Oct 2012	Apr 2014	5.0	0.19	3.3	0.02
	2016#	-	5.0	0.19	0.4	0.02
75 ≤ kW < 130	Oct 2012	Nov 2013	5.0	0.19	3.3	0.02
	2016#	-	5.0	0.19	0.4	0.02
130 ≤ kW < 560	Oct 2011	Apr 2013	3.5	0.19	2.0	0.02
	2015#	-	3.5	0.19	0.4	0.02
#Proposed						

5.1.3.2 China

Emission standards for non-road diesels were adopted in 2007. While the requirements are based on the EU Stage I and Stage II emission standards, they also include small diesel engines. The China emission standards for non-road diesels are presented in Table 5-17 (Ecopoint Inc., 2013l).

Table 5-17: China non-road diesel emission standards

Engine Power	Stage	Date	CO (g/kW.hr)	HC (g/kW.hr)	NMHC+NOx (g/kW.hr)	NOx (g/kW.hr)	PM (g/kW.hr)
< 8 kW	Stage I	Oct 2007	12.3	-	18.4	-	-
	Stage II	Oct 2009	8.0	-	10.5	-	1.0
8 ≤ kW < 18	Stage I	Oct 2007	8.4	-	12.9	-	-
	Stage II	Oct 2009	6.6	-	10.5	-	0.80
18 ≤ kW < 37	Stage I	Oct 2007	8.4	2.1	-	10.8	1.0
	Stage II	Oct 2009	5.5	1.5	-	8.0	0.80
37 ≤ kW < 75	Stage I	Oct 2007	6.5	1.3	-	9.2	0.85
	Stage II	Oct 2009	5.0	1.3	-	7.0	0.40
75 ≤ kW < 130	Stage I	Oct 2007	5.0	1.3	-	9.2	0.70
	Stage II	Oct 2009	5.0	1.0	-	6.0	0.30
130 ≤ kW < 560	Stage I	Oct 2007	5.0	1.3	-	9.2	0.54
	Stage II	Oct 2009	5.0	1.0	-	6.0	0.20

5.1.3.3 India

India introduced emission standards for diesel agricultural tractors in 1999 under Bharat (TREM) and diesel construction machinery in 2007 under Bharat (CEV). Both of these emission standards are largely based on either EU or US emission standards (Ecopoint Inc., 2013m).

The Bharat (CEV) emission standards for construction machinery are presented in Table 5-18, while the Bharat (TREM) emission standards for agricultural tractors are presented in Table 5-19 (Ecopoint Inc., 2013m).

Table 5-18: India non-road diesel emission standards for construction machinery

Engine Power	Date	CO (g/kW.hr)	HC (g/kW.hr)	$NMHC+NO_x$ (g/kW.hr)	NOx (g/kW.hr)	PM (g/kW.hr)
Bharat (CEV) Stage II[a]						
< 8 kW	Oct 2008	8.0	1.3	-	9.2	1.0
8 ≤ kW < 19	Oct 2008	6.6	1.3	-	9.2	0.85
19 ≤ kW < 37	Oct 2007	6.5	1.3	-	9.2	0.85
37 ≤ kW < 75	Oct 2007	6.5	1.3	-	9.2	0.85
75 ≤ kW < 130	Oct 2007	5.0	1.3	-	9.2	0.70
130 ≤ kW < 560	Oct 2007	5.0	1.3	-	9.2	0.54
Bharat (CEV) Stage III[b]						
< 8 kW	Apr 2011	8.0	-	7.5	-	0.80
8 ≤ kW < 19	Apr 2011	6.6	-	7.5	-	0.80
19 ≤ kW < 37	Apr 2011	5.5	-	7.5	-	0.60
37 ≤ kW < 75	Apr 2011	5.0	-	4.7	-	0.40
75 ≤ kW < 130	Apr 2011	5.0	-	4.0	-	0.30
130 ≤ kW < 560	Apr 2011	3.5	-	4.0	-	0.20
[a]These emission standards are based on EU Stage I requirements, but also cover smaller engines that are not regulated under EU Stage I [b]These emission standards are based on US Tier 2 and Tier 3 requirements						

Table 5-19: India non-road diesel emission standards for agricultural tractors

Engine Power	Date	CO (g/kW.hr)	HC (g/kW.hr)	NMHC+NOx (g/kW.hr)	NOx (g/kW.hr)	PM (g/kW.hr)
Bharat (TREM) Stage I						
All	Oct 1999	14.0	3.5	-	18.0	
Bharat (TREM) Stage II						
All	Jun 2003	9.0	-	15.0	-	1.0
Bharat (TREM) Stage III						
All	Oct 2005	5.5	-	9.5	-	0.8
Bharat (TREM) Stage IIIA						
< 8 kW	Apr 2010	5.5	-	8.5	-	0.80
8 ≤ kW < 19	Apr 2010	5.5	-	8.5	-	0.80
19 ≤ kW < 37	Apr 2010	5.5	-	7.5	-	0.60
37 ≤ kW < 75	Apr 2011	5.0	-	4.7	-	0.40
75 ≤ kW < 130	Apr 2011	5.0	-	4.0	-	0.30
130 ≤ kW < 560	Apr 2011	3.5	-	4.0	-	0.20

5.1.3.4 South Korea

South Korea began regulating non-road diesels in 2004 with US Tier 1 emission standards that applied to construction machinery, including excavators, bulldozers, loaders, cranes, graders, rollers and forklifts. In 2005 and 2009, emission standards consistent with US Tier 2 and Tier 3, respectively were adopted for construction machinery. In 2013, agricultural machinery was included in the regulation, in addition to construction machinery, with US Tier 3 emission standards applying to both. In 2015, US Tier 4 emission standards for both construction machinery and agricultural equipment will be included in the regulation (Ecopoint Inc., 2013n).

The South Korea emission standards for construction machinery are presented in Table 5-20, emission standards for agricultural equipment are presented in Table 5-21 and the US Tier 4 emission standards for all non-road diesels are presented in Table 5-22 (Ecopoint Inc., 2013n).

Table 5-20: South Korea non-road diesel emission standards for construction machinery

Engine Power	Date	CO (g/kW.hr)	HC (g/kW.hr)	NMHC+NOx (g/kW.hr)	NOx (g/kW.hr)	PM (g/kW.hr)
Tier 1 (US Tier 1)						
19 ≤ kW < 37	Jan 2004	5.5	-	9.5	-	0.80
37 ≤ kW < 75		5.5	1.3	-	9.2	0.60
75 ≤ kW < 130		5.0	1.3	-	9.2	0.60
130 ≤ kW < 225		5.0	1.3	-	9.2	0.54
225 ≤ kW < 560		5.0	1.3	-	9.2	0.54
Tier 2 (US Tier 2)						
19 ≤ kW < 37	Jan 2005	5.5	-	7.5	-	0.60
37 ≤ kW < 75		5.0	-	7.5	-	0.40
75 ≤ kW < 130		5.0	-	6.6	-	0.30
130 ≤ kW < 225		3.5	-	6.6	-	0.20
225 ≤ kW < 560		3.5	-	6.4	-	0.20
Tier 3 (US Tier 3)						
19 ≤ kW < 37	Jan 2009	5.5	-	7.5	-	0.60
37 ≤ kW < 75		5.0	-	4.7	-	0.40
75 ≤ kW < 130		5.0	-	4.0	-	0.30
130 ≤ kW < 560		3.5	-	4.0	-	0.20

Table 5-21: South Korea non-road diesel emission standards for agricultural equipment

Engine Power	Date	CO (g/kW.hr)	HC (g/kW.hr)	NMHC+NOx (g/kW.hr)	NOx (g/kW.hr)	PM (g/kW.hr)
Tier 3 (US Tier 3)						
225 ≤ kW < 560	2 Feb 2013 2004	3.5	-	4.0	-	0.2
19 ≤ kW < 37	1 Jul 2013	5.5	-	7.5	-	0.60
37 ≤ kW < 75		5.0	-	4.7	-	0.40
75 ≤ kW < 130		5.0	-	4.0	-	0.30
130 ≤ kW < 560		3.5	-	4.0	-	0.20

Table 5-22: South Korea non-road diesel emission standards for non-road engines

Engine Power	Date	CO (g/kW.hr)	HC (g/kW.hr)	NMHC+NOx (g/kW.hr)	NOx (g/kW.hr)	PM (g/kW.hr)
Tier 4 (US Tier 4)						
< 8 kW	1 Jan 2015	8.0	-	7.5	-	0.40
8 ≤ kW < 19		6.6	-	7.5	-	0.40
19 ≤ kW < 37		5.5	-	4.7	-	0.03
37 ≤ kW < 75		5.0	-	4.7	-	0.03
75 ≤ kW < 130		5.0	0.19	-	0.40	0.02
130 ≤ kW < 560		3.5	0.19	-	0.40	0.02

5.1.3.5 Singapore

Regulations have been in place for non-road diesels in Singapore since August 2000. Non-road diesels must comply with EU Stage I, US Tier 1 or Japan Stage 1 standards. Non-road diesel engines are defined to be those diesel engines that are used as the main or auxiliary power source for any equipment or machinery not registered for on-road use, but does not include engines in ships, railway locomotives and aircraft (Ecopoint Inc., 2013o).

5.1.4 South America

This section provides an overview of new emission standards for non-road diesels in South America.

5.1.4.1 Brazil

During 2011, Brazil introduced regulations for non-road diesels, including construction and farm machinery. The Brazil regulations adopted US Tier 3 and EU Stage IIIA emission standards phased in from 2015 to 2019 and these are presented in Table 5-23.

Table 5-23: Brazil non-road diesel emission standards

Engine Power	Date		CO (g/kW.hr)	HC+NO$_x$ (g/kW.hr)	PM (g/kW.hr)
	Construction	Farming			
19 ≤ kW < 37	Jan 2017	Jan 2019	5.5	7.5	0.60
37 ≤ kW < 75	Jan 2015	Jan 2019	5.0	4.7	0.40
75 ≤ kW < 130	Jan 2015	Jan 2017	5.0	4.0	0.30
130 ≤ kW < 560	Jan 2015	Jan 2017	3.5	4.0	0.20

5.2 In-Service Non-Road Diesel Engine Emission Reduction Programs

This section provides examples of in-service emission reduction programs for non-road diesels.

5.2.1 California

In July 2007, the Californian Air Resources Board (CARB) adopted the *Regulation for In-Use Off-Road Diesel-Fueled Fleets* (http://www.arb.ca.gov/msprog/ordiesel/reglanguage.htm) to reduce diesel particulate matter (DPM) and oxide of nitrogen (NO$_x$) emissions from existing self-propelled in-use non-road diesel vehicles (CARB, 2012).

The regulation aims to reduce the emissions of PM and NO_x from in-use non-road diesel vehicles using a range of measures:

- Limits on vehicle idling requiring a written idling policy
- Requirement for all non-road vehicles to be labelled and reported to CARB via an on-line reporting system
- Restrictions on addition of older vehicles to fleets
- Requirements for fleets to reduce emissions by retiring, replacing, repowering or installing verified Diesel Emission Control Strategies (retrofit exhaust aftertreatment).

The regulation applies to all self-propelled diesel non-road vehicles over 25 hp (19 kW) with the following exclusions:

- Personal use equipment
- Vehicles used solely for agriculture
- Vehicles regulated by the Regulation for Mobile Cargo Handling Equipment at Ports and Intermodal Rail Yards (Cargo Handling regulation)
- Emergency operations vehicles, dedicated snow removal vehicles, low-use vehicles (<200 hours/year), and vehicles used for the majority of the time (but not solely) for agricultural purposes must be reported to CARB but are exempt from the performance requirements.

The requirements and compliance dates depend on fleet size calculated by the sum of the horsepower of all vehicles in a fleet. The fleet size categories are:

- Small – Fleet or municipality ≤ 2500 hp (1900 kW) or municipality fleet in low population area, captive attainment area, or non-profit training centre regardless of total horsepower
- Medium – Fleet with total horsepower 2501-5000 hp (1901-3800 kW)
- Large – Fleet with total horsepower ≥ 5001 hp (3801 kW) or all state or federal government fleets regardless of size.

The regulation includes the following emission control requirements:

Idle Reduction

From June 2008 fleets must limit unnecessary idling to 5 minutes with exceptions for vehicles that need to idle when performing work. Medium and large fleets must have a written idling policy.

Reporting and Labelling

From 2009 all fleets must report all non-road vehicles to CARB. A unique equipment identification number (EIN) is assigned by CARB and the fleet must label each vehicle within 30 days. Beginning in 2012 for large fleets, 2016 for medium fleets, and 2018 for small fleets, the regulation requires fleets to annually update and affirm their information with a signed statement.

Addition of Older Vehicles to Fleets

From January 2014 any vehicles added to a fleet must have a US Tier 2 or higher engine. From January 2018 for medium and large fleets, and from January 2023 for small fleets, any vehicles added to a fleet must have a US Tier 3 or higher engine.

Fleet Performance Requirements

The performance requirements begin in January 2014 for large fleets, January 2017 for medium fleets and January 2019 for small fleets. By each compliance deadline, a fleet must demonstrate that it has either met the fleet average target for that year or complied with Best Available Control Technology requirements (BACT). Large fleets have compliance deadlines each year from 2014 through 2023, medium fleets each year from 2017 through 2023, and small fleets each year from 2019 through 2028. The fleet average targets and BACT requirements include:

- **Meeting the fleet average targets** – The fleet average index is an indicator of a fleet's overall emission rate. It is based on the fleet's average NO_x emissions, which is determined by the horsepower and model year of each engine in the fleet. If the fleet average index is equal to or less than the fleet average target for a given year, no further action is required to reduce emissions
- **Complying with BACT requirements** – If a fleet cannot/will not meet the fleet average target in a given year, they may comply with the BACT requirements. A fleet may meet the BACT requirements each year by turning over or retrofitting exhaust aftertreatment on a certain percentage of its total fleet horsepower per year (BACT rate). Turnover means retiring a vehicle, designating a vehicle as permanent low-use (a vehicle used less than 200 hours per year), repowering a vehicle with a higher Tier engine or rebuilding the engine to a more stringent emission standard. Retrofit means installing the highest level of either PM and/or NO_x control verified by CARB. In order to fulfil the BACT requirements for large and medium fleets, where a retrofit is not possible, the vehicle must be turned over. For small fleets, where a retrofit is not possible, the vehicle is exempt from the BACT requirements. The BACT rates for each fleet size are shown in Table 5-24.

Table 5-24: California Best Available Control Technology rates

Large Fleets		Medium Fleets		Small Fleets	
Year	BACT	Year	BACT	Year	BACT
2014	4.8%	2017	8%	2019-2028	10%
2015-2017	8%	2018-2023	10%	-	-
2018-2023	10%	-	-	-	-

5.2.2 Sweden

From 1 January 1999, emission requirements were introduced by several municipalities to reduce the impacts of non-road vehicles and equipment (construction machines, wheel tractors, excavators, lawn movers and hedge cutters) operated in Environmental Zones. Contractors were required to meet certain requirements to be eligible to bid for municipal contracts, including (Ecopoint Inc., 2013g):

- new engines that meet the latest emission standards (Non-road diesels must meet at least EU Stage I or US Tier 1 emission standards), or
- retrofit older engines with certified emission control equipment. Emission control equipment typically includes either diesel oxidation catalysts (DOC) or DOC combined with diesel particulate filters (DPF) with emission reduction required presented in Table 5-25.

Table 5-25: Sweden non-road diesel retrofit emission reduction requirements

Equipment	Pollutant	Emission Reduction
Particulate Filter	Particulate Matter (PM)	80%
Oxidation Catalyst	Hydrocarbons (HC)	80%
New non-road diesels that meet EU Stage I or US Tier 1 were required to retrofit exhaust aftertreatment after 8 years of age The maximum allowable age of an engine equipped with a DOC was 14 years The maximum allowable age of an engine equipped with DOC and DPF combination was 16 years		

5.3 New Non-Road Diesel Engine Capital Costs

The US Tier 2 PM emission standards for non-road diesels are typically achieved through engine design (such as improved combustion chamber design and advanced fuel injection systems) but do not require exhaust aftertreatment (Ecopoint Inc., 2013b).

US Tier 2 and Tier 3 NO_x emission standards for non-road diesels are typically achieved with a combination of engine optimisation and some injection timing retard (relative to the optimum for maximum fuel economy). On some US Tier 3 compliant engines, cooled exhaust gas regeneration (EGR) has also been adopted. These emission control technologies are relatively low cost and add only modest additional amounts to US Tier 2 & Tier 3 compliant engine costs (Ecopoint Inc., 2013b).

To meet the US Tier 4 and EU Stage IV emission standards for non-road diesels, advanced exhaust aftertreatment in conjunction with advanced engine design for both PM and NO_x are typically required (Ecopoint Inc., 2013b).

The US Tier 4 final PM emission standards typically require exhaust aftertreatment, including either a diesel oxidation catalyst (DOC) or a diesel particulate filter (DPF), although some manufacturers have developed engines of greater than 560 kW that can meet the PM emission standards without aftertreatment (Ecopoint Inc., 2013b).

To meet the US Tier 4 final NO_x emission standards for engines from 56 to 560 kW, manufacturers often utilise selective catalytic reduction (SCR), which requires urea injection. Selective catalytic reduction is sometimes used in conjunction with cooled EGR. Engines below 56 kW and above 560 kW can be designed to meet the US Tier 4 final NO_x emission standards with either cooled EGR or SCR alone (Ecopoint Inc., 2013b).

The use of DOC, DPF, SCR, cooled EGR and advanced engine design impose significant additional costs on the manufacture of US Tier 4 final compliant engines (Ecopoint Inc., 2013b).

The incremental costs of US Tier 1, Tier 2, Tier 3 and Tier 4 compliant engines relative to US Tier 0 have been estimated from:

- United States Environmental Protection Agency (USEPA) *Final Regulatory Analysis: Control of Emissions from Nonroad Diesel Engines* (USEPA, 2004)
- NSW Environment Protection Authority (EPA) *Reducing Emissions from Non-Road Diesel Engines Information Report* (EPA, 2014).

Since varying incremental costs have been reported, the following sections provide a separate overview of new non-road diesel engine costs.

5.3.1 USEPA Final Regulatory Analysis: Control of Emissions from Nonroad Diesel Engines

The USEPA developed detailed cost estimates for the incremental cost of manufacturing US Tier 4 final compliant non-road diesels relative to US Tier 2 & Tier 3 (USEPA 2004). Costs were broken down into the following categories:

- **Engine fixed costs** - These include engine research and development costs, engine production line tooling costs and engine certification costs
- **Engine variable costs** - These include the per engine unit manufacturing costs for the specific emission control components such as exhaust aftertreatment systems (DOC, NO_x adsorber

catalysts, DPF and associated hardware), EGR systems, closed crankcase ventilation (CCV) systems and common rail fuel systems, where these were not already commonly utilised

- **Equipment fixed costs** - These include the equipment redesign required to package and support the additional emission control hardware, retooling costs and product support literature and training
- **Equipment variable costs** - These include the per equipment unit manufacturing costs arising from additional hardware and increased assembly time.

A detailed analysis of each cost component was performed in consultation with engine and emission control technology manufacturers. For the engine fixed costs and variable costs, NO_x and PM emission control technologies were assumed for each engine power range and these are presented in Table 5-26 (USEPA 2004).

Table 5-26: USEPA assumed US Tier 4 emission control technology

Engine Power	NO_x Control	PM Control
19 ≤ kW < 56	Cooled EGR	DPF
56 ≤ kW < 560	NO_x adsorber catalyst	DPF
≥ 560 kW	Cooled EGR	DPF

For the research and development (R&D) costs, the analysis took into account the R&D already undertaken for on-road diesel emission control technologies. The R&D costs were assumed to be incurred in the five year period prior to the introduction of the US Tier 4 emission standards. Engine fixed costs were amortised over a five year cost recovery period using a seven per cent capital cost (USEPA 2004).

For the engine variable costs, the emission control systems were broken down into primary components and costed separately. For instance, the total costs for DPF were broken down into the individual costs of each component, including: DOC (placed ahead of the DPF); DPF substrate, including washcoating and canning of the substrate; platinum metal catalyst; the materials for the canning (DPF housing); a back pressure sensor; regeneration system; warranty and stock holding etc. For each complete emission control system, linear regression was used to develop formulae that express cost as a function of engine displacement (USEPA 2004).

Since the USEPA analysis was undertaken, some manufacturers have been able to meet the US Tier 4 PM emission standards with either a DOC, or with no PM exhaust aftertreatment. Assuming that a DPF is required to meet the US Tier 4 PM emission standards for all non-road diesels, results in a significant overestimation of the costs. Conversely, manufacturers have not adopted NO_x adsorber catalysts but have developed advanced in-cylinder emission control technologies utilising combinations of cooled EGR and SCR (for engines of 56-560 kW). However, the cost implications of this are not clear. It is possible that SCR has been adopted due to its ability to deliver the required engine functionality but this may be accompanied by higher costs.

The USEPA analysis assumed that manufacturers would not use the Transitional Program for Equipment Manufacturers (TPEM) in the US federal emission standards (Ecopoint Inc., 2013b & USEPA, 2012a) or the averaging, banking and trading provisions, both of which provide some level of cost savings, and hence the resulting cost data would overestimate the costs to manufacturers (USEPA 2004).

The USEPA analysis reported both a near term and long term cost for both fixed and variable costs. The fixed costs are assumed to be recovered over a five year period from the introduction of a specific technology. Where emission standards are phased in, the fixed costs are recovered during the phase in period and then during the five years following 100% compliance with the new emission standard.

For variable costs, the near term assumes a 3% warranty claim rate while the long term assumes a 1% warranty claim rate. Additionally, a “learning curve” effect is incorporated that assumes cost efficiencies in production accrue over time. In the longer term costs are therefore predicted to decrease. The near term variable costs are applied to the first two years of production, thereafter the long term variable costs are used.

The near term and long term costs reported in the USEPA analysis are presented in Table 5-27 and Table 5-28, respectively in 2002 USD. The fixed costs presented in Table 5-27 are the average over the total fixed cost recovery period which can range from five to ten years.

Table 5-27: USEPA near term per engine US Tier 4 incremental cost summary (2002 USD)

Engine Power	Fixed Engine Costs		Fixed Equipment Costs		Variable Engine Costs† Cost = a + b x Displacement		Variable Equipment Costs
	Cost	Years	Cost	Years	a	b	
56 ≤ kW < 75	$76	7	$105	12	$439	$261	$48
75 ≤ kW < 130	$75	7	$165	12	$439	$261	$49
130 ≤ kW < 225	$182	8	$268	13	$439	$261	$60
225 ≤ kW < 450	$460	8	$483	13	$439	$261	$114
450 ≤ kW ≤560	$1,020	8	$1,085	13	$439	$261	$120
> 560 kW	$799	9	$932	14	$321	$201	$103

†Variable engine costs apply for the first two years from implementation of emission standards

Table 5-28: USEPA long term per engine US Tier 4 incremental cost summary (2002 USD)

Engine Power	Variable Engine Costs Cost = a + b x Displacement (L)		Variable Equipment Costs
	a	b	
56 ≤ kW < 75	$352	$205	$48
75 ≤ kW < 130	$352	$205	$49
130 ≤ kW < 225	$352	$205	$60
225 ≤ kW < 450	$352	$205	$114
450 ≤ kW ≤ 560	$352	$205	$120
> 560 kW	$240	$155	$103

The US Tier 3 to Tier 4 incremental costs for a range of engine sizes was calculated from the USEPA near term costs presented in Table 5-27. The costs have been (1) adjusted to 2012 USD using the US producer price index for manufacture of heavy duty trucks (BLS, 2014) and (2) converted to AUD using the average 2012 USD to AUD exchange rate (RBA, 2014). A plot of the US Tier 3 to Tier 4 incremental costs is shown in Figure 5-1.

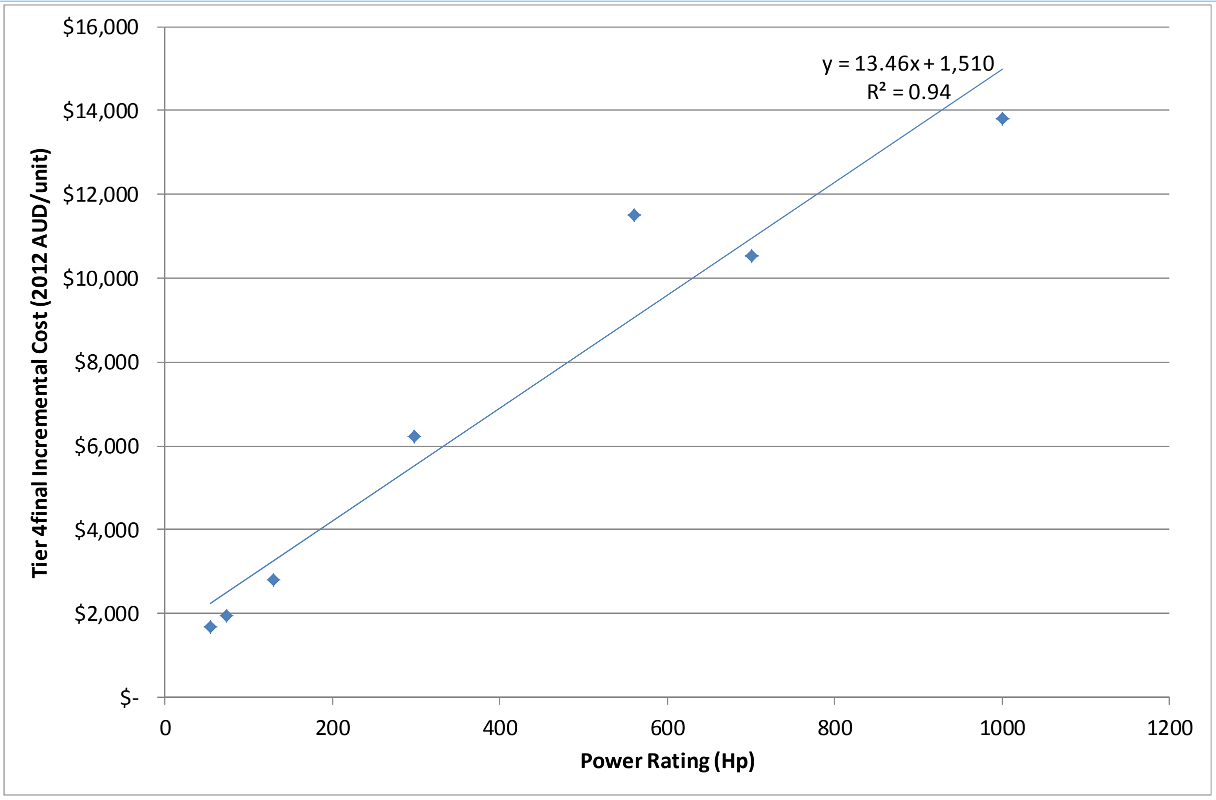


Figure 5-1: US Tier 4 incremental costs relative to Tier 3 (2012 AUD)

5.3.2 EPA Reducing Emissions from Non-Road Diesel Engines Information Report

Environ was commissioned by the NSW Environment Protection Authority (EPA) to prepare the *Reducing Emissions from Non-Road Diesel Engines Information Report* (EPA Information Report) for the introduction of national non-road diesel emission standards. The EPA Information Report addresses the impact on new equipment prices by introducing US emission standards. The EPA Information Report reviewed US and EU regulatory impact analyses and also sought information from a wide range of Australian suppliers and representatives of non-road diesel original equipment manufacturers (OEM) (EPA, 2014).

The data received from Australian suppliers is in the form of incremental retail costs relative to uncertified engines (US Tier 0) for a bare engine (plus required aftertreatment) that meets US Tier 2 to Tier 4 emission standards. US Tier 1 compliant engines were assumed to be the same cost as non-compliant US Tier 0 engines. All incremental costs include emissions related costs only, that is, additional costs incurred that are required to meet a higher level of US emission standards certification (EPA, 2014).

The data in the final draft C-RIS is shown in Figure 5-2 as incremental retail costs relative to US Tier 0 & Tier 1 compliant engines as a function of engine power. For each US Tier emission standard, linear regression was used to develop formulae from the final draft C-RIS data that express cost as function of engine power and the equation variables are presented in Table 5-29 (EPA, 2014).

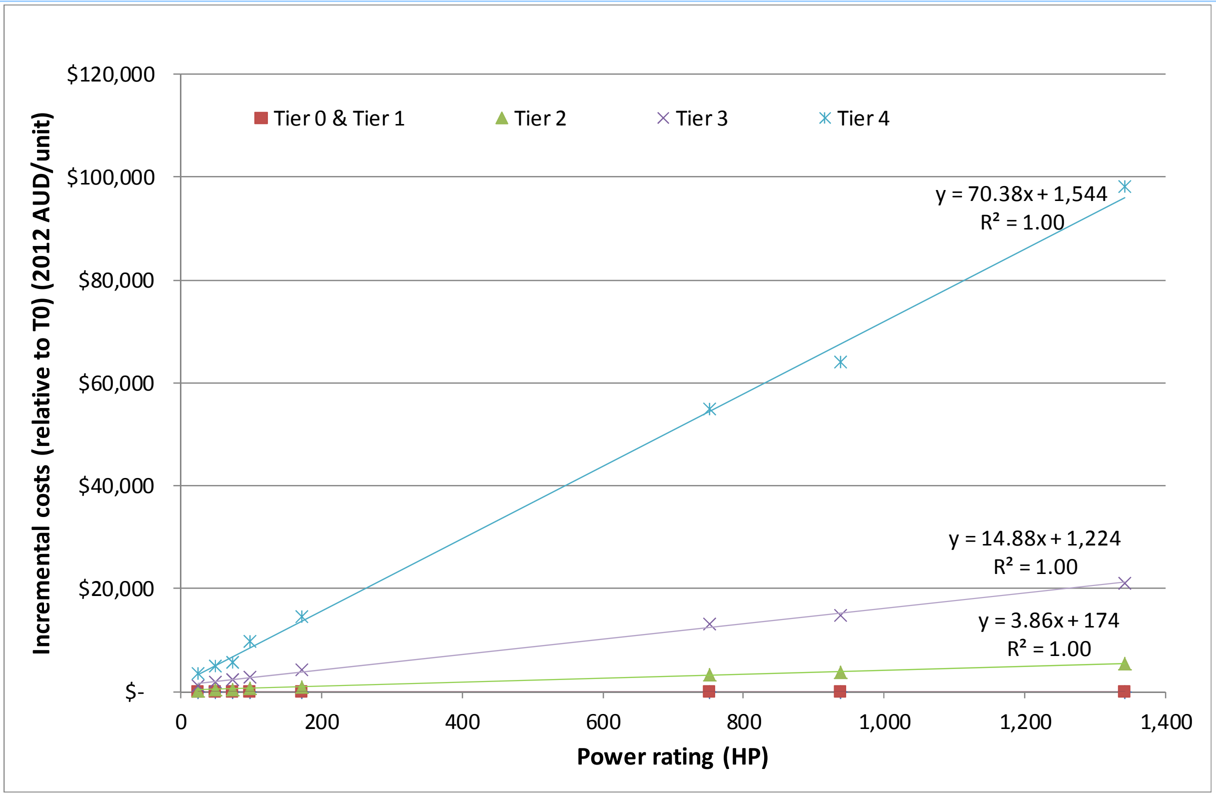


Figure 5-2: US Tier 2, Tier 3 & Tier 4 compliant incremental engine costs relative to Tier 0 & Tier 1 compliant engines (2012 AUD) – linear regression

Table 5-29: US Tier 2, Tier 3 & Tier 4 compliant incremental engine costs relative to Tier 0 & Tier 1 compliant engines (2012 AUD) - formulae

Tier	Incremental Engine Costs Cost = m x Horsepower (Hp) + b	
	m	b
Tier 0	0	0
Tier 1	0	0
Tier 2	3.86	174
Tier 3	14.88	1,224
Tier 4	70.38	1,544

5.3.3 USEPA Final Regulatory Analysis vs. EPA Information Report

A comparison of the US Tier 3 to Tier 4 final incremental costs from the USEPA Final Regulatory Analysis (see Section 5.3.1 for further details) and EPA Information Report (see Section 5.3.2 for further details) is shown in Figure 5-3. The EPA cost data sourced from Australian non-road diesel equipment suppliers is considerably higher than the USEPA estimates. In the cost benefit analysis (CBA) (see Section 8 for further details), the EPA Information Report cost data have been used as these are more up to date (2013 vs. 2004) and specific to the Australian market.

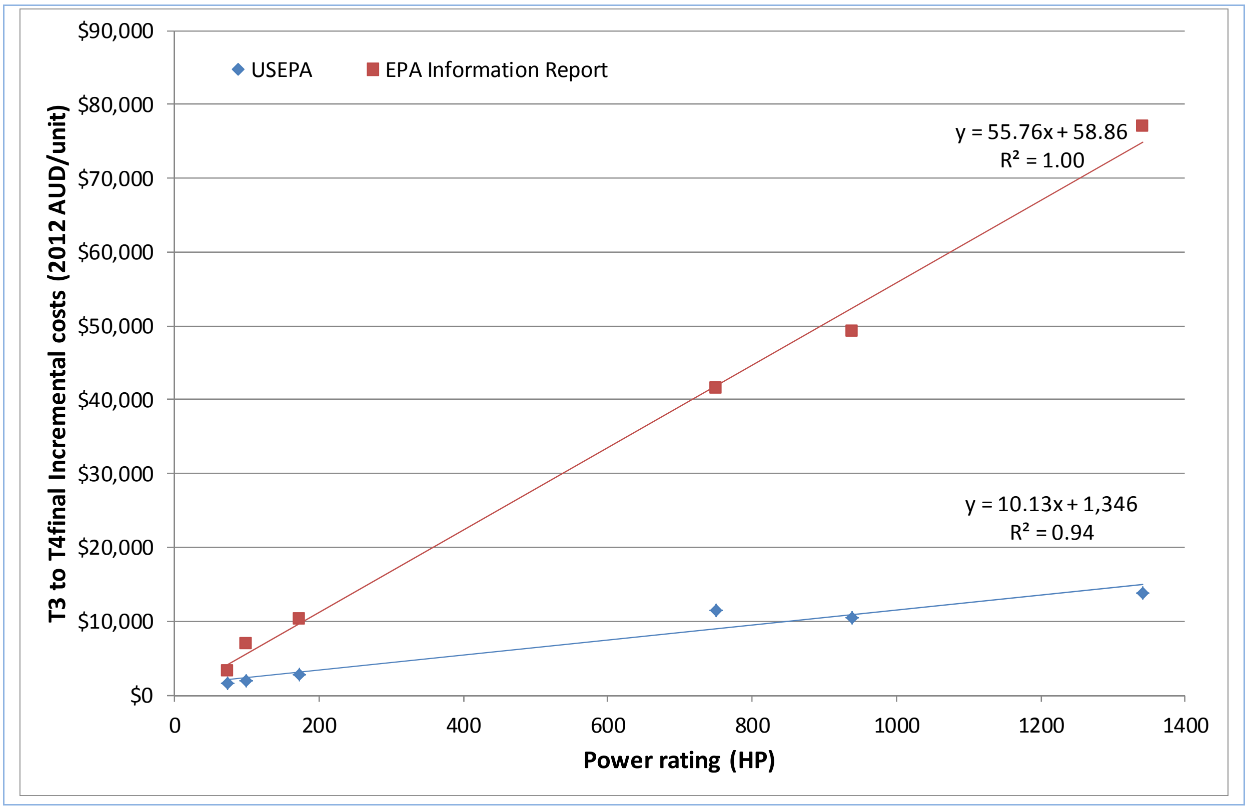


Figure 5-3: US Tier 4 incremental costs relative to Tier 3 - USEPA final regulatory analysis vs. EPA Information Report (2012 AUD)

5.4 New Non-Road Diesel Engine Maintenance Costs

For US Tier 4 compliant engines, incremental maintenance costs are largely incurred when cleaning DPF and servicing/replacing CCV filters (USEPA, 2004). Since there is no substantial change in engine architecture and exhaust aftertreatment technologies between US Tier 2 and Tier 3 compliant engines when compared to US Tier 0 and 1, incremental maintenance costs have not been applied to US Tier 3 or earlier (EPA, 2014).

For US Tier 4 compliant engines, the EPA Information Report estimates that maintenance costs range from 0.4% for 19-37 kW equipment up to 2.5% for equipment greater than 560 kW. Maintenance costs for equipment 37-560 kW are estimated at 1.2%. These incremental annual maintenance costs are expressed as percentages of the retail cost of Tier 4 compliant equipment (EPA, 2014). Since retail costs of equipment were not available for this project, data from the USEPA Tier 4 Final Regulatory Analysis has been used. These incremental annual maintenance costs are expressed as percentages of diesel cost and are presented in Table 5-30 (USEPA, 2004).

Table 5-30: USEPA maintenance costs for US Tier 4 compliant engines

Horsepower (Hp)	Maintenance costs expressed as % diesel cost		
	DPF maintenance	CCV maintenance	Net maintenance
< 25 Hp	0.00	0.00	0.00
25 ≤ Hp < 50	3.43	0.00	3.43
50 ≤ Hp < 75	2.39	0.15	2.54
75 ≤ Hp < 175	1.19	0.45	1.64
175 ≤ Hp < 300	0.30	0.30	0.60

Horsepower (Hp)	Maintenance costs expressed as % diesel cost		
	DPF maintenance	CCV maintenance	Net maintenance
300 ≤ Hp < 600	0.15	0.15	0.30
600 ≤ Hp < 750	0.15	0.30	0.45
≥ 750 Hp	0.00*	0.30	0.30

*The USEPA Tier 4 Final Regulatory Analysis assumed 0.30% since these engines would use DPF, although some manufacturers have been able to meet the US Tier 4 PM emission standards with either a DOC, or with no PM exhaust aftertreatment so no DPF maintenance has been applied (refer to Section 5.3.1 and Section 5.5.1.1 for further details)

5.5 New Non-Road Diesel Engine Operating Costs

This section provides estimates of fuel and urea consumption and costs associated with adopting higher levels of US emission standards certification for non-road diesels.

5.5.1 Fuel consumption and costs

The engine design and associated calibration required to meet more stringent emission standards can require some trade-offs in fuel consumption. In general, engine design can achieve more stringent PM emission standards through improved fuel injection and combustion chamber design, which also results in increased engine efficiency and lower fuel consumption. However, meeting more stringent NO_x emission standards with in cylinder control (excluding EGR) can have a negative impact on fuel consumption. Most manufacturers did not introduce EGR to meet more stringent NO_x emission standards until US Tier 4, so many US Tier 2 and Tier 3 engines are less fuel efficient than US Tier 0 and Tier 1 engines, since fuel injection timing was often retarded in these engines. Exhaust gas recirculation and SCR aftertreatment both provide the means to reduce NO_x emissions with limited or no fuel consumption impact (Eastwood, 2008; USEPA, 1994; USEPA, 1998 & USEPA, 2004).

A number of information sources were reviewed to determine the relative fuel consumption of engines certified to the various US Tiers and this information is summarised in the following sections.

5.5.1.1 USEPA regulatory impact analysis

The USEPA performed regulatory impact analyses for the introduction of the US Tier 1 (USEPA, 1994), US Tier 2 & Tier 3 (USEPA, 1998) and US Tier 4 (USEPA, 2004) non-road diesel emission standards. These reports examine the likely fuel consumption impacts associated with the adoption of more stringent non-road diesel emission standards.

Tier 1 regulatory impact analysis

The Tier 1 regulatory impact analysis (USEPA, 1994) concluded the US Tier 1 emission standards would have no impact on fuel consumption. The USEPA considered that to meet the NO_x emission standards, some degree of fuel injection timing retard may be required, with an associated increase in fuel consumption of 1% to 5%. The USEPA believed however, the increase in fuel consumption associated with any injection timing retard would be recovered with other technology improvements such as increased fuel injection pressure and improved fuel injector nozzle design, increased turbocharger boost, improved aftercooling and possibly engine derate. Taking all these factors into account, the USEPA concluded the introduction of US Tier 1 emission standards would be fuel consumption neutral (USEPA, 1994).

Tier 2 & 3 regulatory impact analysis

The Tier 2 and Tier 3 regulatory impact analysis (USEPA, 1998) examined a wide range of technology improvements expected to be adopted to meet the new emission standards, including:

- engine modifications (retarded fuel injection timing, combustion chamber design, compression ratio)
- advanced fuel injection controls (increased fuel injection pressures, fuel injector nozzle design, electronically controlled fuel injectors, fuel injection rate shaping, common rail and multiple fuel injection systems)
- exhaust gas recirculation (EGR) for US Tier 3 (cooled for engines >75 kW)
- improved charge air density (improved turbocharging and charge air aftercooling).

Most of these technologies were expected to improve engine efficiency providing an offset to any increases in fuel consumption associated with retarded fuel injection timing. The combination of electronic controls with advanced fuel injection, in particular fuel injection rate shaping, were expected to assist in meeting the NO_x emission standards with either no impact or even improved fuel economy. The single largest benefit to fuel economy was considered to be due to adoption of either air to water or air to air charge air cooling with a fuel consumption benefit of 3% to 6%.

In the final cost effectiveness analysis of the predicted likely technology package to meet US Tier 2 & Tier 3, all technologies were treated as fuel consumption neutral even though the analysis had predicted fuel savings, due primarily to the larger engines (USEPA, 1998).

Tier 4 regulatory impact analysis

The Tier 4 regulatory impact analysis (USEPA, 2004) included an assessment of the fuel consumption impact of the predicted emission control technologies required to meet US Tier 4 emission standards.

The technologies predicted by the USEPA to meet the US Tier 4 emission standards for NO_x and PM are shown in columns two and three of Table 5-26. Since that time, considerable technology development has occurred and engine manufacturers have adopted alternative solutions. The solutions employed for those engines that have been certified to US Tier 4 final emission standards as at January 2014 are shown in the last two columns of Table 5-31. The main changes are that NO_x adsorbers were not adopted, with most manufacturers adopting cooled EGR combined with SCR and either cooled EGR or SCR alone for engines above 560 kW. For PM in engines from 130-560 kW, all manufacturers have adopted a DOC and DPF combination, while for engines above 560 kW some manufacturers have been able to comply with the US Tier 4 final emission standards with either no specific PM aftertreatment or with just a DOC.

Table 5-31: USEPA predicted and actual certified US Tier 4 final emission control technology

Engine Power	RIA Predicted Technology (2004)		Actual Certified Technology (2013)	
	NO_x Control	PM Control	NO_x Control	PM Control
130 ≤ kW < 560	NO_x Adsorber	DPF	Cooled EGR + SCR	DOC + DPF
> 560 kW	Cooled EGR	DPF	Cooled EGR or SCR	None or DOC

For US Tier 4 compliant engines, the USEPA estimated increases in fuel consumption as follows: 2% increase due to the use of a DPF; 1% due to increased pumping losses (higher exhaust back pressure); and 1% allowance for active filter regeneration. The USEPA claimed these estimates as conservatively high. However, for those engines between 56 and 560 kW using a NO_x adsorber, a gain in efficiency was predicted that offset half of the DPF fuel consumption impact. This gain in fuel efficiency was estimated relative to US Tier 2 & Tier 3 compliant engines using fuel injection timing retard and cooled EGR. The USEPA estimated a net fuel consumption increase of 1% maximum for US Tier 4 technologies relative to US Tier 2 & Tier 3 (USEPA, 2004).

Selective catalytic reduction has subsequently been adopted for NO_x control by engine manufacturers and has proven to be more effective than NO_x adsorbers. The use of SCR would be expected to provide some opportunity to optimise the engine further for fuel economy. Also, for engines above 560 kW, DPF are not necessary to meet US Tier 4 PM emission standards, so the estimated impact of a 2% increase in fuel consumption would not apply. The estimated fuel consumption impact of actual certified NO_x and PM emission control technologies relative to the USEPA analysis is presented in Table 5-32.

Table 5-32: USEPA predicted and actual certified US Tier 4 fuel consumption impact

Engine Power	USEPA Predicted Fuel Consumption Impact Relative to Tier 2 & 3 (2004)			Actual Certified Technology Estimated Fuel Consumption Impact (2013)		
	NO_x Control	PM Control	Net Impact	NO_x Control	PM Control	Net Impact
130 ≤ kW < 560	NO_x Adsorber -1% FC	DPF +2% FC	+1%	Cooled EGR + SCR -2% FC	DOC + DPF + 2% FC	0%
> 560 kW	Cooled EGR 0% FC	DPF + 2% FC	+2%	Cooled EGR + SCR Cooled EGR -1% FC	None or DOC 0% FC	-1%

5.5.1.2 EPA Information Report

The EPA Information Report investigated the fuel consumption impacts associated with the introduction of national non-road diesel emission standards (EPA, 2014). Industry information was sought from Australian non-road equipment and engine suppliers on the relative fuel consumption impacts of the technologies used for US Tier 0 to Tier 4 compliant engines. Information was received from suppliers representing four major equipment/engine manufacturers. The EPA Information Report uses information which is based on the industry stakeholder submissions and this is summarised in Table 5-33.

Table 5-33: EPA Information Report relative fuel consumption data

Tier	Relative Fuel Consumption
Tier 0	100%
Tier 1	100%
Tier 2	105%
Tier 3	100%
Tier 4	95[†]%

[†] Offset by a urea injection rate of 1.4% to 3.5% of fuel consumption when using SCR

5.5.1.3 CARB & USEPA engine certification database

The Californian Air Resources Board (CARB) *Off-Road Certification Database* (http://arbis.arb.ca.gov/msprog/offroad/cert/cert.php) was queried to obtain fuel efficiency data from a sample of engines from major manufacturers. The certifications listed in the CARB database are generally identical to those in the USEPA *Non-road Large Compression Ignition (NRCI) Engine Certification Database* (http://www.epa.gov/otaq/certdata.htm#nrci). The certification test data contained in the CARB database includes fuel rates at rated power speed and in most cases at rated torque speed. The in-service fuel efficiency comparison may vary depending on duty cycle, however this data is considered to give a good indication of the likely trends between US Tier 1 to 4 final compliant engines. Engine models were selected where US Tier 1 to Tier 4 final compliant engines of similar displacement and power rating had been certified. For most engine families, many different ratings were/are available and specific configurations were selected where the rated power and rated torque speeds were the same or similar across the US Tiers.

The brake specific fuel consumption (BSFC) at rated power and rated torque was calculated for each engine model and then averaged across each US Tier. The fuel consumption relative to US Tier 1 is shown in Table 5-34. It is notable that the Komatsu 15 litre engine utilised EGR for US Tier 3 and has clearly achieved a decrease in fuel consumption. No Caterpillar or Cummins engine used EGR prior to US Tier 4.

As at 2 December 2014, only four US Tier 4 final high power (≥ 560 kW) engines had been certified in the US, although it is understood the major OEM engine manufacturers have largely completed development work and have engines in field trials. All OEMs except one have largely opted for engine configurations with SCR and no DPF for the very high power (> 1 MW) engines. Selective catalytic reduction allows the OEMs to optimise the engine for low engine out PM and maximum fuel efficiency. While this results in high engine out NO_x, SCR is very effective in meeting the US Tier 4 final non-road diesel NO_x emission standards. Relative to US Tier 2 engines, where the fuel efficiency is compromised by retarding the injection timing to meet the NO_x emission standards, US Tier 4 final engines are expected to be more fuel efficient.

Table 5-34: CARB certification data relative fuel consumption

Engine Make & Displacement	Power Range	Relative Average Fuel Consumption (average of rated power and rated torque bsfc)			
		Tier 1	Tier 2	Tier 3	Tier 4f
Caterpillar 15 L	130-560 kW	100%	101%	107%	103%
Cummins 15 L	130-560 kW	100%	107%	114%	105%
Komatsu 15 L	130-560 kW	100%	103%	98%	97%
Cummins 19 L[a]	130-560 kW	100%	104%	112%	101%
Caterpillar 27 L[a]	130-560 kW	100%	103%	102%	101%[c]
Caterpillar 32 L[b]	>560 kW	100%	100%		98.5%[c]
Caterpillar 59 L	>560 kW	100%	100%		104%[c]
Cummins 50 L	>560 kW	100%	105%		100%
Cummins 60 L	>560 kW	100%	102%		*103%*[d]
Caterpillar 78 L	>560 kW	100%	100%/94%[e]		
Caterpillar 85L	>560 kW		100%[f]		
MTU/Detroit 90/95 L	>560 kW	100%	100%		
Average all engines		**100%**	**102%**	**107%**	**101%**
Average >560 kW engines		**100%**	**101%**		**101%**

[a] Prior to US Tier 4 these engines were certified to ≤560 kW

[b] Compared to 27L Tier 1 engine

[c] EGR engine

[d] *US Tier 4 interim under averaging, banking and trading (ABT) provisions, same emissions as US Tier 2 which meet US Tier 4i PM limit*

[e] These engines meet US Tier 1 emission limits and are certified to US Tier 2 under ABT provisions and certified for the 2014 model year. The US Tier 2 certified engines are built in two specs, the electronic controlled engine being considerably more fuel efficient

5.5.1.4 Engine and original equipment manufacturers

Engine and original equipment manufacturer (OEM) literature was reviewed, in particular Cummins and Caterpillar, for non-road diesel engines ranging in size from 75 to 4,200 horsepower (Hp). The literature includes details about engine design, exhaust emission control technologies, equipment applications and changes in fuel consumption associated with more stringent US Tiers and this information is presented in Table 5-35. When compared to US Tier 2 compliant engines, no changes in fuel consumption are claimed for US Tier 3 compliant engines. US Tier 4i compliant engines are claimed to consume up to 5% (average 3%) less fuel when compared to US Tier 3 compliant engines, while US Tier 4f compliant engines are also claimed to consume up to 5% (average 4%) less fuel when compared to US Tier 4i compliant engines.

Table 5-35: Engine and original equipment manufacturer (OEM) fuel consumption

Manufacturer	Horsepower (Hp)		PM/NO_x Technology	Existing Tier	Replacement Tier	Fuel consumption (%)*	
	Minimum	Maximum				Minimum	Maximum
Cummins	75	751	Various/SCR	Tier 3	Tier 4f	-7	-9
Cummins	75	173	DOC/Cooled EGR	Tier 3	Tier 4i	0	-5
Cummins	75	173	DOC/Cooled EGR	Tier 3	Tier 4i	0	-5
Cummins	75	174	DOC/Cooled EGR	Tier 3	Tier 4i	0	-5
Cummins	85	173	DOC/Cooled EGR	Tier 3	Tier 4i	0	-5
Cummins	121	400	DOC/SCR	Tier 3	Tier 4f	-3	-8
Cummins	140	400	DOC/Cooled EGR & SCR	Tier 3	Tier 4f	0	-5
Cummins	146	310	DOC/Cooled EGR & SCR	Tier 4i	Tier 4f	0	-3
Cummins	174	751	DOC & DPF/Cooled EGR	Tier 3	Tier 4i	0	-5
Cummins	175	600	DPF/Cooled EGR	Tier 3	Tier 4i	0	-5
Cummins	190	400	DPF/Cooled EGR	Tier 3	Tier 4i	0	-5
Cummins	215	305	-	Tier 2	Tier 3	0	0
Cummins	230	400	DOC/Cooled EGR & SCR	Tier 4i	Tier 4f	0	-1.5
Cummins	290	600	DPF/Cooled EGR	Tier 3	Tier 4i	0	-5
Cummins	400	675	DOC & DPF/SCR	Tier 3	Tier 4f	-4	-9
Cummins	400	600	DOC & DPF/Cooled EGR	Tier 3	Tier 4i	0	-5
Cummins	450	675	DPF/Cooled EGR & SCR	Tier 4i	Tier 4f	0	-5
Cummins	751	4200	-/SCR	Tier 2	Tier 4f	0	-7
Caterpillar	24.7	37	DOC & DPF/-	Tier 3	Tier 4f	-5	-10
Caterpillar	42.1	61	DOC & DPF/-	Tier 3	Tier 4f	-5	-10
Caterpillar	60.3	75	DOC & DPF/-	Tier 3	Tier 4f	-5	-10
Caterpillar	75	115	DOC/SCR	Tier 3	Tier 4f	-5	-10
Caterpillar	93.9	173.5	DOC/SCR	Tier 3	Tier 4f	-5	-10
Caterpillar	93.9	173.5	DPF/SCR	Tier 3	Tier 4f	-5	-10
Caterpillar	119.3	173.5	DOC & DPF/-	Tier 3	Tier 4i	0	-5
Caterpillar	202	302	DOC & DPF/Cooled EGR & SCR	Tier 3	Tier 4f	-5	-10

Manufacturer	Horsepower (Hp)		PM/NO$_x$ Technology	Existing Tier	Replacement Tier	Fuel consumption (%)*	
	Minimum	Maximum				Minimum	Maximum
Caterpillar	250	275	DOC & DPF/Cooled EGR & SCR	Tier 3	Tier 4f	-5	-10
Caterpillar	350	350	DOC & DPF/Cooled EGR & SCR	Tier 3	Tier 4f	-5	-10
Caterpillar	440	440	DOC & DPF/Cooled EGR & SCR	Tier 3	Tier 4f	-5	-10
Caterpillar	540	540	DOC & DPF/Cooled EGR & SCR	Tier 3	Tier 4f	-5	-10
Caterpillar	630	755	DOC & DPF/Cooled EGR & SCR	Tier 3	Tier 4f	-5	-10
Caterpillar	690	1275	DOC & DPF/Cooled EGR	Tier 3	Tier 4i	0	-5
Caterpillar	800	1200	DOC/Cooled EGR	Tier 3	Tier 4f	-5	-10
MTU	1240	3100	-/Cooled EGR	Tier 1	Tier 4f	0	0

*References
http://cumminsengines.com/brochure-download.aspx?brochureid=327
http://cumminsengines.com/brochure-download.aspx?brochureid=34
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http://www.rrpowersystems.com/fileadmin/fm-dam/tognum/press/2013/MTU_S4000C_Tier4_EN.pdf

5.5.1.5 Summary of fuel consumption impacts

The USEPA regulatory impact analysis, EPA Information Report, CARB/USEPA certification database and Cummins/Caterpillar estimated impacts of US Tier 0 to Tier 4 emission standards on fuel consumption in non-road diesel engines are summarised in Table 5-36.

Table 5-36: Summary of fuel consumption impacts on US Tier 0 – Tier 4 emission standards

Estimate Source	Relative Fuel Consumption (<560kW/>560kW)				
	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4f[†]
EPA Information Report[††]	100%/100%	100%/100%	105%/105%	100%/-	95%/95%
USEPA regulatory impact analyses[†††]	100%/100%	100%/100%	100%/100%	100%/-	100%/99%
CARB/USEPA certification database[††††]	100%/100%	100%/100%	103%/104%	106%/-	102%/101%
Engine and original equipment manufacturers (OEM)[†††††]	-/-	-/-	100%/100%	100%/-	97%/96%
Relative efficiency used in cost-benefit analysis	**100%/100%**	**100%/100%**	**102%/102%**	**101.5%/-**	**98.5%/97.5%**

[†] Offset by a urea injection rate of 1.4% to 3.5% of fuel consumption when using SCR

[††] The US Tier 4 estimates obtained from the equipment suppliers are likely to include fuel efficiencies and productivity improvements from technologies and features additional to those of the bare engine system, e.g. idle reduction strategies, automatic gear shifting strategies etc.

[†††] The USEPA regulatory impact analyses only considered the direct impact of new technologies introduced to meet emission standards and was stated to be conservative

[††††] This data is for bare engines and will not include other technologies introduced by original equipment manufacturers (OEM) in US Tier 4 compliant equipment. Does not include data on the expected SCR high power engines (> 2000 Hp) that consume more than 45% of fuel in NSW open-cut coal mines.

[†††††] Relative to US Tier 2

5.5.1.6 Fuel costs

The Australian Institute of Petroleum (AIP) publishes retail and terminal gate price (TGP) data for diesel across Australia. Average price data for NSW/National retail and Sydney/National TGP are presented in Table 5-37 (AIP, 2014a) and Table 5-38 (AIP, 2014b), respectively.

Table 5-37: Average diesel retail price in NSW and Australia

Average Diesel Retail Price in cents/Litre (inclusive of GST)		
Calendar Year	NSW	National
2012	147.9	150.6

Table 5-38: Average diesel terminal gate price in Sydney and Australia

Average Diesel Terminal Gate Price in cents/Litre (inclusive of GST)		
Calendar Year	Sydney	National
2012	138.5	138.4

The minimum, maximum and average differences in city vs. country diesel retail prices are presented in Table 5-39 (AIP, 2014c). The national average difference of 3.2 cents/Litre is taken to be equivalent to the additional haulage costs from Sydney to those locations where coal mines are located in NSW.

Table 5-39: Minimum, maximum and average differences in city vs. country diesel retail prices

City vs. Country Diesel Retail Price Differences in cents/Litre (inclusive of GST)	
Minimum	1.5
Maximum	4.0
National average	3.2

The current diesel excise tariff rate is presented in Table 5-40 (http://www.ato.gov.au/Business/Excise/). Coal mines are able to claim a fuel tax credit, which is equivalent to the diesel excise tariff rate (http://www.ato.gov.au/Business/Fuel-schemes/In-detail/Fuel-tax-credits---for-GST-registered-businesses/Calculating-and-record-keeping/Fuel-tax-credit-rates-and-eligible-fuels/).

Table 5-40: Diesel excise tariff rate

Excise Tariff Rate		
Diesel (other than biodiesel)	38.14	cents/Litre

A baseline 2012 calendar year diesel price of 1.13 AUD that would be paid by NSW coal mines has been estimated from the NSW average retail price (147.9 cents/Litre), plus the national average city vs. country retail price (3.2 cents/Litre) and minus the excise tariff rate (38.14 cents/Litre).

The diesel price in future years have been forecast from the baseline 2012 calendar year diesel price of 1.13 AUD using US Energy Information Administration (EIA) forecast petroleum product prices (EIA, 2013) and these are presented in Table 5-41.

Table 5-41: Forecast coal mine diesel price (2012 AUD)

Year	Diesel Price (2012 AUD)	Year	Diesel Price (2012 AUD)
2012	$1.13	2022	$1.19
2013	$1.05	2023	$1.20
2014	$1.03	2024	$1.22
2015	$1.04	2025	$1.24
2016	$1.06	2026	$1.25
2017	$1.08	2027	$1.27
2018	$1.10	2028	$1.29
2019	$1.12	2029	$1.30
2020	$1.14	2030	$1.32
2021	$1.16		

5.5.2 *Adblue consumption and costs*

For US Tier 4 compliant engines, SCR exhaust aftertreatment technology is likely to be used in 100% of 75 to 750 Hp class (Ecopoint Inc., 2013b; USEPA, 2004 & USEPA, 2012a) and 50% to 100% of greater than 750 Hp class (Ecopoint Inc., 2013b; USEPA, 2004 & USEPA, 2012a; Cummins Inc., 2012 & MTU, 2014) equipment. Selective catalytic reduction uses a water based 32.5% solution of urea to reduce NO_x emissions and this solution is known as either Adblue or Diesel Exhaust Fluid (DEF). Adblue consumption equivalent to 2.5% (< 750 Hp) and 3 to 6% (≥ 750 Hp) of diesel consumption is quoted by OEMs. A fleet weighted average Adblue consumption of 1.4% to 3.5% of diesel consumption has been calculated for the NSW coal mining fleet reported in the survey of EPA-licensed coal mines (EPA, 2013b). Adblue consumption expressed as a percentage of diesel consumption is presented for relevant engine horsepower ranges in Table 5-42.

Table 5-42: Adblue consumption for US Tier 4 compliant engines

Horsepower (Hp)	Adblue consumption expressed as % diesel consumption*#
< 25 Hp	0
25 ≤ Hp < 50	0
50 ≤ Hp < 75	0
75 ≤ Hp < 175	2.5
175 ≤ Hp < 300	2.5
300 ≤ Hp < 600	2.5
600 ≤ Hp < 750	2.5
≥ 750 Hp	1.25 to 3.6
Fleet Weighted Average	**1.4 to 3.5**

*References
NSW Environment Protection Authority (EPA) *Reducing Emissions from Non-Road Diesel Engines Information Report* (EPA Information Report) (EPA, 2014)
http://parts.cat.com/parts/fluids/def
http://www.cumminsfiltration.com/html/en/literature/product_literature/asia/additives.html
http://www.dieselnet.com/news/2011/05cummins.php
#For US Tier 4 compliant engines, SCR exhaust aftertreatment technology is likely to be used in 100% of 75 to 750 Hp class (Ecopoint Inc., 2013b; USEPA, 2004 & USEPA, 2012a) and 50% to 100% of greater than 750 Hp class (Ecopoint Inc., 2013b; USEPA, 2004 & USEPA, 2012a; Cummins Inc., 2012 & MTU, 2014) equipment

Adblue retail prices and delivery costs have been obtained from Caltex (Caltex, 2013 & Caltex, 2014) for 1,000, 5,000 and 10,000 Litre bulk deliveries to Singleton and Muswellbrook in the NSW Hunter Valley and these are presented in Table 5-43. These locations have been chosen for delivery costs, since this is where significant coal mining takes place (68.5% of 2012 NSW coal production was in the Hunter Valley LGA of Cessnock, Great Lakes, Lake Macquarie, Muswellbrook and Singleton (EPA, 2013b & DRE, 2013)).

Table 5-43: Adblue retail price (2012 AUD)

Adblue volume (Litre)	Price (exclusive of GST) (2012 AUD/Litre)	Delivery Singleton (exclusive of GST) (2012 AUD/Litre)	Delivery Muswellbrook (exclusive of GST) (2012 AUD/Litre)	Total Price (inclusive of GST) (2012 AUD/Litre)*
1,000	$0.93	1.51	1.66	$2.85
5,000	$0.63	0.30	0.31	$1.04
10,000	$0.54	0.16	0.18	$0.78

*Includes price in 2012 AUD/Litre plus delivery to Muswellbrook in 2012 AUD/Litre. 10% GST has been used

A baseline 2012 calendar year Adblue price of 0.78 AUD that would be paid by NSW coal mines has been estimated from the 10,000 Litre retail price (54 cents/Litre), plus the Muswellbrook delivery price (18 cents/Litre) with 10% goods and services tax (GST) added.

The Adblue price for future years have been forecast from the baseline 2012 calendar year Adblue price of 0.78 AUD using US Energy Information Administration (EIA) forecast petroleum product prices (EIA, 2013) and these are presented in Table 5-44. Forecast diesel prices have been used in the absence of forecast Adblue price data.

Table 5-44: Forecast coal mine Adblue price (2012 AUD)

Year	Adblue Price (2012 AUD)	Year	Adblue Price (2012 AUD)
2012	$0.78	2022	$0.82
2013	$0.80	2023	$0.83
2014	$0.79	2024	$0.85
2015	$0.72	2025	$0.86
2016	$0.73	2026	$0.87
2017	$0.75	2027	$0.88
2018	$0.76	2028	$0.89
2019	$0.78	2029	$0.90
2020	$0.79	2030	$0.91
2021	$0.80		

5.5.3 *Adblue storage tank and dispenser costs*

The weekly diesel consumption at NSW open cut coal mines ranges from about 22,500 litres to nearly 3 million litres (EPA, 2013b). At a fleet weighted average Adblue consumption of 1.4% to 3.5% of diesel consumption, the weekly Adblue consumption at individual NSW coal mine sites ranges from about 300 to 100,000 litres.

The cost of portable self-bunded Adblue storage tanks with integral high volume (300 Litre/min) dispensers was obtained from Transtainer (Transtainer, 2014). The Adblue storage tank and dispenser costs for a range of Adblue storage tank sizes are presented in Table 5-45.

Table 5-45: Adblue storage tank and dispenser costs (2012 AUD)

Adblue Storage Tank Size (Litre)	Adblue Storage Tank and Dispenser Cost (2012 AUD)
10,000	$38,147
20,000	$66,757
40,000	$85,831

A number of Adblue storage tanks and dispensers have been assigned to each coal mine in order to provide one week of Adblue supply. Larger coal mines have been assigned up to eight (5 by 10,000 litre and 3 by 20,000 litre) Adblue storage tanks and dispensers, with some co-located with in-pit diesel storage tanks, while the smaller coal mines have been assigned one 10,000 litre Adblue storage tank and dispenser. The total cost to equip all NSW open-cut coal mines with Adblue storage tanks and dispensers in order to cater for a fleet made up entirely of US Tier 4 non-road diesels has been estimated to be $3.0 million (2012 AUD).

6 IN-SERVICE NON-ROAD DIESEL ENGINE EMISSION CONTROL TECHNOLOGIES AND COSTS

This section provides a summary of in-service exhaust aftertreatment technologies and capital, maintenance and operating costs for diesel non-road vehicles and equipment (non-road diesels). Companies that develop and manufacture or supply and install retrofit exhaust aftertreatment equipment for non-road diesels are also listed and discussed.

6.1 Diesel Engine Exhaust Aftertreatment Technologies

The exhaust aftertreatment equipment commercially available to reduce emissions of diesel particulate matter (DPM) is described in this section. Since the health impact of diesel exhaust is dominated by PM, which is the focus of this project, only equipment that directly reduced DPM is discussed in this report. Information on exhaust aftertreatment equipment to reduce PM, oxides of nitrogen (NO_x), carbon monoxide (CO) and volatile organic compounds (VOC) in diesel exhaust is widely available and those sources reviewed for PM, include:.

- DieselNet (www.dieselnet.com)
- Manufacturers of Emission Controls Association (www.meca.org)
- Association for Emission Control by Catalyst (www.aecc.eu).

6.1.1 Diesel oxidation catalysts

Diesel oxidation catalysts (DOCs) are the simplest form of diesel exhaust aftertreatment equipment available for the reduction of PM emissions and are completely maintenance free.

DOCs were first used in the 1970s on underground mining diesel equipment to reduce gas phase emissions of CO and hydrocarbons (HC). With the introduction of lower sulfur diesel fuel, DOCs were optimised to additionally provide some reduction of DPM by oxidising the organic fraction. In on-road applications, DOCs became common on light duty diesel vehicles in Europe during the 1990s and were OEM fitment on some US heavy duty engines to assist in meeting the US 1994 PM standard of 0.10 g/bhp.hr. DOCs were later also fitted to some heavy duty engines to meet the US 2004 heavy duty PM standard.

All exhaust catalysts work on the same fundamental principle, that is, to promote the reaction of undesirable exhaust pollutants to less harmful levels. The active catalyst is normally a noble metal, which increases the rate of chemical reaction of the reactants by reducing the activation energy required to start the reaction.

DOCs promote the reaction (or oxidation) of CO and HC by using the oxygen present in the diesel exhaust to produce carbon dioxide (CO_2) and water (H_2O). DOCs do not oxidise or reduce any appreciable amounts of the carbonaceous soot component (solid or insoluble/non-volatile fraction) of DPM (refer to Section 2.1.2 for further details) but oxidise the HC component (soluble or volatile fraction) adsorbed onto the surface of the solid particles. This HC component of DPM is termed the soluble organic fraction (SOF). DOCs typically achieve PM reductions of 15 to 30% and reduce diesel exhaust odour significantly (DieselNet, 2012 & Joshi et. al., 2011).

Certain types of DOC may also remove SOF by HC cracking, where the larger long chain HCs are cracked into smaller more volatile compounds that do not adsorb as readily onto the solid particles and are emitted as gas phase HC (DieselNet, 2012).

An undesirable reaction promoted by DOCs is the oxidation of the diesel fuel sulfur to sulfur trioxide (SO_3) and subsequent formation of sulfuric acid (H_2SO_4), which results in an increased PM emissions. This occurs under high exhaust temperature conditions (>350-400 °C) with higher sulfur diesel fuels. While earlier DOCs were designed to supress sulfate formation with higher sulfur diesel fuels (>350 ppm), the introduction of ultra-low sulfur diesel fuel (<10 ppm) has effectively eliminated this issue and DOCs are now able to be optimised for SOF and gaseous emission reduction.

Diesel oxidation catalysts consist of a ceramic or metallic honeycomb substrate structure with many small parallel channels as shown in Figure 6-1 (DieselNet, 1998 & 2004). The substrate typically has 200-400 channels per square inch of cross section to provide a large surface area for contact of the exhaust gases with the catalyst. The substrate is coated with a porous inorganic coating termed the washcoat that generates an extremely large surface area, upon which the noble metal catalyst material is impregnated as shown in Figure 6-2. The washcoat most commonly used is alumina with some incorporating zeolite or ceria for SOF cracking. For modern DOCs, platinum is the most common noble metal catalyst used, which sometimes has a palladium component (DieselNet, 2000).

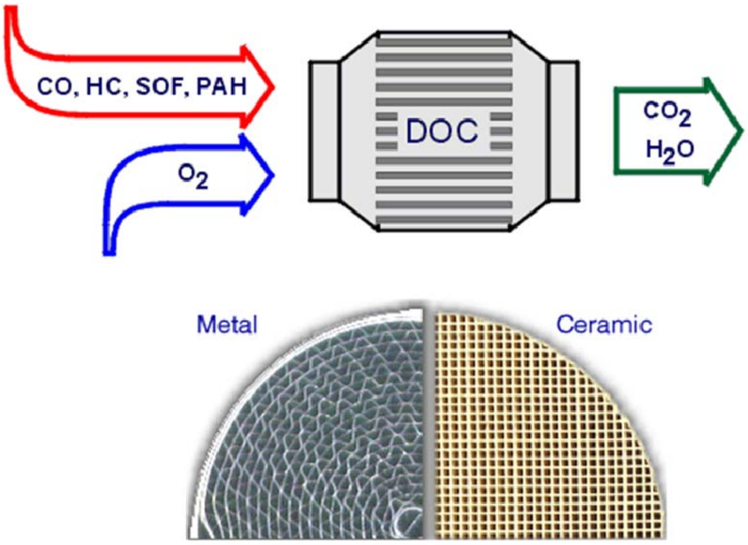


Figure 6-1: Schematic and examples of DOC substrates

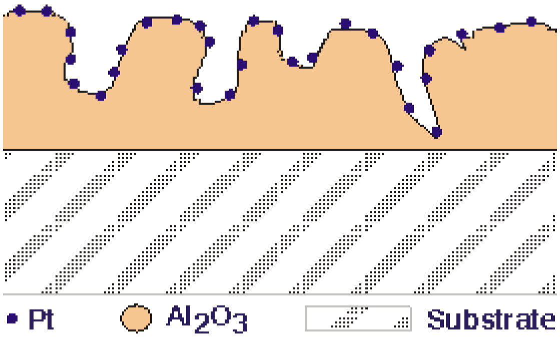


Figure 6-2: Schematic of washcoat and platinum catalyst deposited on the catalyst substrate

All catalysts are relatively inactive below a certain exhaust gas temperature, which is known as the light off temperature. The CO and HC conversion efficiency as a function of temperature for a typical DOC is shown in Figure 6-3 (DieselNet, 2012). The maximum conversion efficiency is dependent on the type of catalyst, its loading, the cell density and the size of the catalyst. In order to maintain high conversion efficiency, DOCs are generally mounted as close as possible to the exhaust manifold.

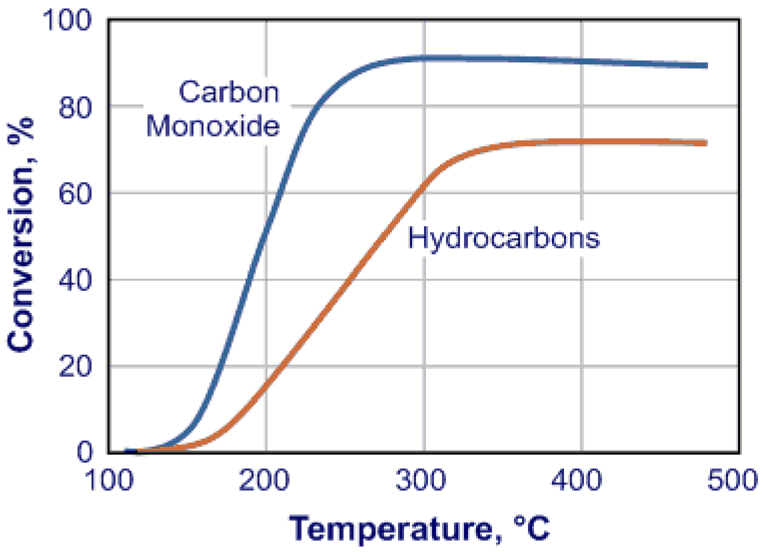


Figure 6-3: CO and HC conversion efficiency as a function of exhaust temperature for a typical DOC

6.1.2 Partial diesel particulate filters

The partial DPF (pDPF) may be considered to be half way between a DOC (refer to Section 6.1.1 for further details) and a wall flow DPF (refer to Section 6.1.3 for further details). Partial DPF are also referred to as open filters, flow through filters or particle oxidation catalysts.

Partial DPF can capture and store soot particles for sufficient time to allow for catalytic oxidation, while having open flow through passages that allow exhaust gases to pass even if the soot storage capacity is saturated. Hence, contrary to wall flow DPF, even if conditions for passive regeneration of the trapped soot do not occur, the pDPF will not block so they are essentially maintenance free.

However, the compromise for pDPF is they exhibit a much lower PM reduction than a wall flow DPF, with efficiencies of 50% being typical when measured under regulatory test cycles (DieselNet, 2011a & Joshi et. al., 2011). The regulatory test cycles used to evaluate the performance of pDPF are generally regarded as the best case performance scenario and their efficiency has been shown to decline as more soot accumulates on the filter media under conditions of low regeneration. On the other hand, as a worst case the PM reduction efficiency can reduce to zero or even cause short periods of elevated PM emissions when accumulated soot can blow off the filter (DieselNet, 2011a; TNO, 2009 & Joshi, et. al., 2011).

Various filter media have been developed for use as pDPF including ceramic or metallic foams, wire mesh and metal fleeces. An upstream oxidation catalyst is normally used to generate nitrogen dioxide (NO_2) to oxidise soot particles trapped on the filter media. While the catalyst increases NO_2 emissions, total NO_x emissions are unchanged.

An example of pDPF filter media manufactured by EmiTec is shown in Figure 6-4 (http://www.emitec.com/en/technology/catalyst-substrates/pm-metalit.html). This design consists of alternating layers of corrugated metal foil and a sintered metal fleece. The channels through the corrugated metal are shaped in such a way as to cause solid particles to impinge on the metal fleece, while maintaining an open flow path to allow gases to flow even if the fleece becomes clogged with soot.

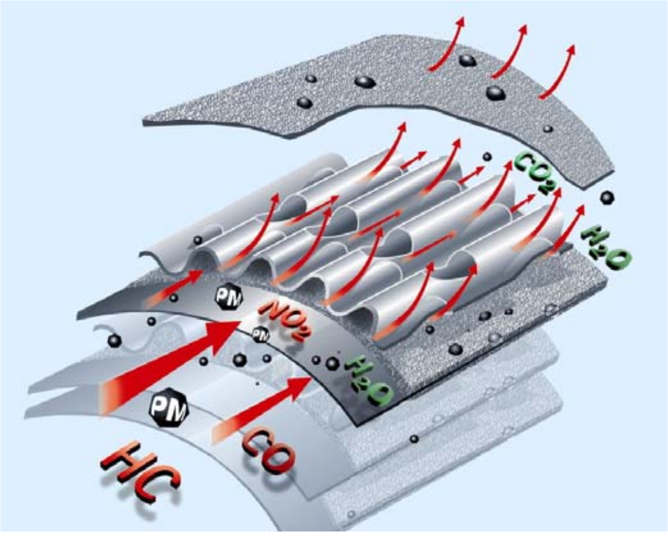


Figure 6-4: EmiTec PM-Metalit partial diesel particulate filter structure

As with other exhaust catalysts, low sulfur diesel fuel (<50 ppm) is required to avoid excessive sulfate particle production and to ensure maximum NO_2 is produced to oxidise trapped soot. Exhaust gas temperatures above 250 °C are typically required to oxidise trapped soot. Carbon monoxide and HC emissions are significantly reduced by pDPF, while an increase in NO_2 emission typically occurs as with all catalytic exhaust aftertreatment equipment. While the catalyst increases NO_2 emissions, total NO_x emissions are unchanged.

6.1.3 Diesel particulate filters

6.1.3.1 DPF operating principle

Diesel particulate filters (DPFs) physically filter the PM present in diesel exhaust. A DPF consists of a ceramic monolith similar to that of a DOC but with adjacent channels plugged at alternate ends as shown in Figure 6-5 (DieselNet, 2005). The exhaust gas flows in the open end of the channel, through the wall of the channel and out the open end of the adjacent channel. The walls of the channels are designed with tightly controlled porosity that allows the gaseous exhaust to flow through but filters or traps the PM. For this reason DPFs are sometimes called wall flow filters or diesel particulate traps.

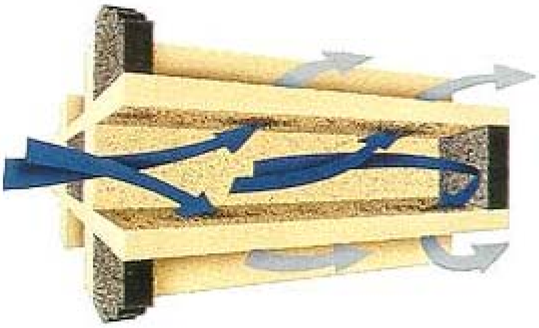


Figure 6-5: Schematic of wall flow DPF monolith structure

Wall flow DPFs are highly effective at reducing both PM mass and number, with many test results in the literature showing greater than 95% reduction in both (Lanni et. al., 2001; Chatterjee et. al., 2001; Joshi et. al., 2011 & DieselNet, 2011b). DPFs have been fitted to many thousands of vehicles since the late 1990s in retrofit programs in Europe and the United States. Since early to mid-2000s, new on-road diesel vehicle/engine emission standards have required the fitment of DPFs as OEM equipment to the majority of light and heavy duty diesel vehicles, totalling tens of millions of DPF.

Although the porosity and sizing of the DPF is designed to provide normal back pressure to the engine, over time the soot particles will build up in the channels resulting in a rise in back pressure and ultimately blockage of the filter unless the soot is removed. The removal of soot from the filter is referred to as regeneration and is typically achieved thermally, whereby the soot is oxidised (or burned off) to gaseous compounds, primarily to CO_2. Several mechanisms are employed to achieve filter regeneration and these may be passive or active, which can be either continuous or periodic:

- **Passive DPF regeneration** **-** Passive DPF regeneration requires a sufficiently high engine duty cycle to ensure oxidation of the trapped soot and regeneration of the DPF occurs. Whilst careful selection and sizing of the DPF based on measured exhaust gas temperatures during representative operating conditions will generally ensure satisfactory DPF regeneration, there is a very small risk of increased filter clogging if extended periods of unusually low engine load operation occur.

  Passive DPF regeneration is the most common method of soot removal from the DPF, whereby the heat required to burn off the trapped soot is provided by the exhaust gas itself. As the temperature required to oxidise soot with oxygen is in excess of 600 °C (a temperature that is never reached by modern diesel engines) catalysts are employed to lower the soot oxidation temperature to within the operating range of diesel engine exhaust. Two catalytic methods are used to oxidise the soot, either with oxygen (refer to Section 6.1.3.2 for further details) or nitrogen dioxide (refer to Section 6.1.3.3 for further details) based oxidation and they may be used either separately or together (refer to Section 6.1.3.4 for further details).

- **Active DPF regeneration** **-** OEM engine and equipment manufacturers prefer to use active DPF regeneration as a safety backup to normal passive DPF regeneration of catalysed DPF to avoid problems with low load engine operation. The pressure drop across the DPF is monitored and if an excessive build-up of soot is detected, an active regeneration cycle is triggered. Active DPF regeneration is typically achieved using the engine management system to raise the exhaust gas temperature via either late in-cylinder diesel injection in the case of common rail and electronically controlled injection systems (which is most common) or injection of diesel into the exhaust system ahead of the trap (which is less common). The additional fuel in either case is catalytically oxidized on the DPF resulting in a temperature rise which promotes regeneration of the trapped soot.

  OEM systems are designed and the engine management calibrated to maximize passive DPF regeneration. Under most normal operating conditions, the overall fuel consumption increase due to active DPF regeneration is barely measurable or approximately 0.1% for most applications (http://cumminsengines.com/cummins-particulate-filter).

  Active DPF regeneration systems are also available for retrofit applications and employ the same principle as OEM, except injection of diesel into the exhaust system is used ahead of the DPF.

6.1.3.2 Catalysed DPF (oxygen based soot oxidation)

To enable oxidation of soot with oxygen, catalysed DPFs (CDPFs) are used where the filter monolith of the DPF is coated with a noble metal catalyst, most commonly platinum and sometimes in conjunction with small amounts of rhodium for sulfate suppression. An example of a CDPF is shown in Figure 6-6 (http://ect.jmcatalysts.com/Catalysed-soot-filter-CSF-johnson-matthey).

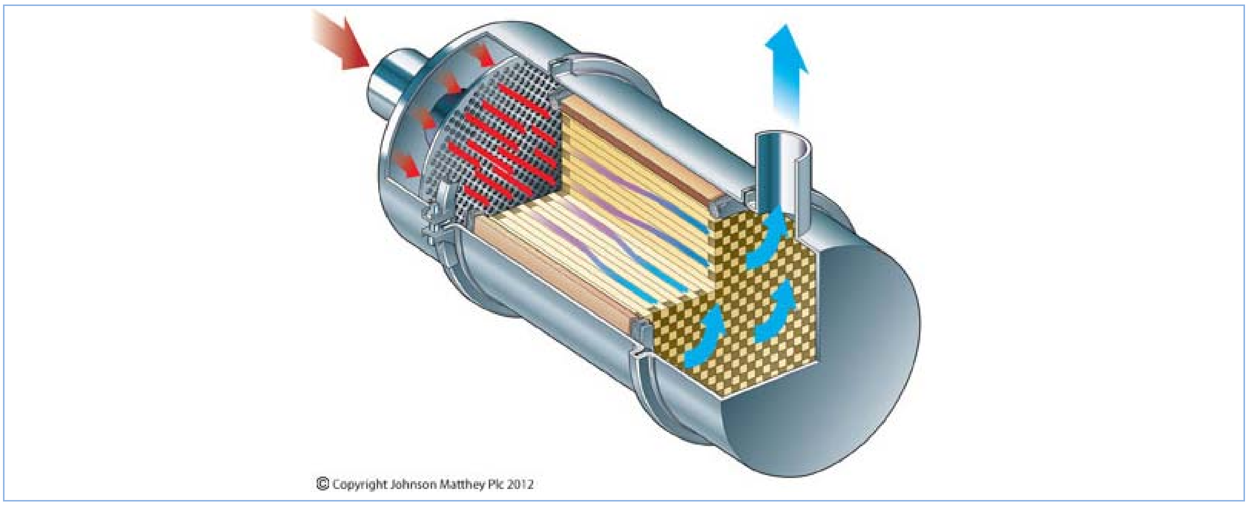


Figure 6-6: Catalysed DPF by Johnson Matthey

The catalytic coating lowers the temperature required for the oxidation of the trapped soot to around 300-400 °C using oxygen alone. It is also thought that some soot oxidation occurs by reaction of NO_2 that is catalytically generated within the filter (refer to Section 6.1.3.3 for further details). Manufacturers of CDPFs typically state that an exhaust temperature of greater than 350 °C is required for more than 30% of the time, or 280 °C for more than 50% of the time, in order to provide sufficient regeneration to maintain low soot levels on the filter. The exhaust temperature and percent of the time can be lowered, if engine out PM emissions and diesel fuel sulfur content are reduced.

In high load operating conditions oxidation of the soot and regeneration of the CDPF is effectively constant and this is termed continuous regeneration. Where the exhaust temperatures fluctuate, soot will accumulate during low temperature operation and then rapidly regenerate during high temperature operation and this is termed periodic regeneration.

Platinum based CDPFs require diesel fuels with less than 50 ppm sulfur to avoid sulfur poisoning and excessive production of sulfate PM emissions. They also benefit from less than 10 ppm sulfur in terms of ability to regenerate and minimise sulfate PM emissions.

6.1.3.3 Oxidation catalyst plus DPF (nitrogen dioxide soot oxidation)

Nitrogen dioxide (NO_2) is able to oxidise soot at much lower temperatures than oxygen, with significant oxidation rates occurring from as low as 250 °C. Johnson Matthey pioneered this technology with the continuously regenerating trap (CRT) in the early 1990s. Since the amount of NO_2 in diesel exhaust is only about 5-10% of total NO_x emissions, a catalyst that is active in oxidising nitric oxide (NO) to NO_2 is placed ahead of the uncatalysed filter monolith to raise NO_2 levels up to about 50% of total NO_x. While the catalyst increases NO_2 emissions, total NO_x emissions are unchanged.

A schematic of the Johnson Matthey CRT is shown in Figure 6-7 (http://ect.jmcatalysts.com/Continuously-regenerating-trap-CRT-johnson-matthey). The patent for this approach has subsequently expired and most major DPF manufacturers now offer CRT type NO_2 regeneration DPF.

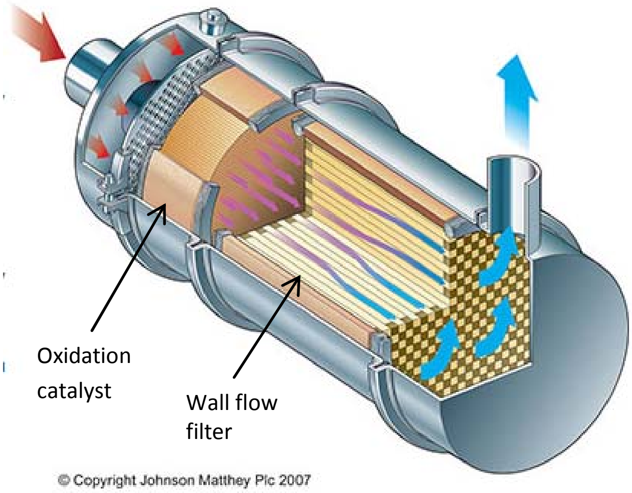


Figure 6-7: NO_2 oxidation based CRT by Johnson Matthey

As for CDPFs, CRTs require the use of diesel fuels with less than 50 ppm sulfur and show improved regeneration performance with less than 10 ppm sulfur as required by national fuel quality standards in Australia (Attorney-General's Department, 2009a; 2009b & 2010).

The exhaust temperature requirements specified for CRT type DPFs are typically greater than 250 °C for more than 40% of the time, which is significantly lower than that of CDPFs. For this reason, CRT type DPFs are more suitable for lower duty operation and reduce the risk of filter clogging through insufficient regeneration. Johnson Matthey specifies a minimum NO_x:PM ratio of 20:1 (http://ect.jmcatalysts.com/Continuously-regenerating-trap-CRT-johnson-matthey) to ensure sufficient NO_2 is available to oxidise the soot.

6.1.3.4 Combination passive DPF

Some manufacturers offer DPF that combine both NO_2 and oxygen based oxidation for maximum low temperature regeneration performance. These DPF use an upstream oxidation catalyst to generate increased levels of NO_2, in combination with a catalysed filter monolith to promote oxygen based oxidation and further generation of NO_2 within the filter. While the catalyst increases NO_2 emissions, total NO_x emissions are unchanged. Johnson Matthey specify an exhaust temperature requirement of greater than 210 °C for more than 40% of the time (http://ect.jmcatalysts.com/Coated-continuously-regenerating-trap-CCRT-johnson-matthey) compared to greater than 250 °C for more than 40% of the time for their standard CRT. They also state that a lower NO_x:PM ratio can be tolerated with the combined equipment.

6.1.3.5 Impact of DPF on gaseous emissions

In addition to their high PM reduction capability, CDPFs and CRT type DPFs are highly effective at reducing CO and HC, with 80-90% efficiencies common. A negative side effect can be elevated levels of tailpipe NO_2. The USEPA and CARB both stipulate that retrofit exhaust aftertreatment equipment must not increase tailpipe NO_2 by more than 20% of the baseline total NO_x emissions. While the catalyst increases NO_2 emissions, total NO_x emissions are unchanged.

6.1.3.6 DPF maintenance

Whilst a well designed and sized DPF system will successfully oxidise the soot and regenerate the DPF, the inorganic ash component of the DPM is unable to be burnt off and over time accumulates on the filter. Much of the ash arises from inorganic compounds in the engine oil additives, and for this reason low ash oil is specified for engines equipped with DPF. Periodically the DPF must be removed from the vehicle/equipment and cleaned. Cleaning is typically achieved by blowing out with compressed air.

Diesel particulate filter cleaning intervals primarily depend on oil consumption, average engine load and DPF size. High oil consumption decreases cleaning intervals, as does higher average engine loads. A higher DPF volume to engine displacement ratio will invariably increase the relative ash storage capacity of a DPF, so a DPF sized for low exhaust back pressure will have longer cleaning intevals. Caterpillar specifies a minimum ash cleaning interval on their US Tier 4 compliant C15 industrial non-road diesel engine of 500,000 km or 5,000 hours for the US EPA07 compliant C15 on-road diesel engine. Cummins specifies a DPF cleaning interval of up to 300,000 to 500,000 km, 250,000 litres of fuel or 4,500 hours for their ADR80/03 certified ISX15 on-road diesel engine. Cleaning intervals for high power diesel engines (≥ 560 kW) used at NSW open-cut coal mines will vary from these applications according to their relative oil consumption, average engine load and DPF size.

6.1.3.7 DPF retrofit considerations

The most important consideration in terms of retrofitting in-service equipment with DPFs is establishing the exhaust temperature profile during normal operations. This will provide the aftertreatment supplier with information about the suitability of retrofitting the equipment and selection and sizing of the DPF. For instance equipment with a high duty cycle may be suitable for a CDPF which is typically smaller than a CRT type DPF. Equipment with lower duty cycles may need a combined oxidation catalyst plus catalysed filter approach and in the extreme case may also need an active regeneration system.

The DPF should be sized so the engine OEM exhaust back pressure specification is not exceeded. Diesel particulate filter manufacturers provide standard sizing tables based on engine exhaust gas flow rate to keep DPF back pressure to a specified level. A DPF that is too small will increase fuel consumption (~0.1% for every 1 kPa average increase in back pressure), decrease cleaning interval and may lead to an increase in exhaust gas temperature and possible premature turbocharger seal failure if exhaust back pressure is very high (DieselNet, 2007). Diesel particulate filters used in retrofit applications are typically sized to a retrofit industry standard maximum exhaust back pressure limit of 10 kPa for engines greater than 500 kW as specified in the European Verification of Emission Reduction Technologies (VERT) scheme (DieselNet, 2007 & VERT, 2014). It should be noted that a DPF provides around 25 dBa exhaust noise attenuation, so any existing muffler may be omitted or reduced in size and back pressure will reduce as a consequence.

A DPF installation should always include a back pressure monitoring system, preferably an electronic system that can determine a back pressure alert threshold based on the percentage of time that the exhaust back pressure is above a specified level.

All engines that are candidates for DPF retrofit should be in good operating condition. Excessive oil consumption will result in excessive build-up of non-combustible ash. The injection system, turbocharger and inlet system should all be in good condition to avoid excessive engine out PM emissions. DPFs should never be regarded as a substitute for good basic maintenance practices.

While most DPFs specify a maximum diesel fuel sulfur content of 50 ppm, diesel fuel with less than 10 ppm sulfur required by national fuel quality standards in Australia (Attorney-General's Department, 2009a; 2009b & 2010) will maximise the effectiveness and regeneration ability of all types of DPFs.

6.1.4 Exhaust aftertreatment retrofit considerations

Some important factors to consider when planning the retrofit of exhaust aftertreatment on non-road diesels are summarised below:

- **Desired PM reduction** - DOC reduce diesel exhaust PM by 15 to 30%, pDPF by 30 to 50% and DPF by more than 90%. DOC reduce only the soluble organic faction (SOF) of the PM, pDPF reduce SOF and small amounts of the insoluble carbonaceous soot, while DPF are highly effective at reducing both soluble and insoluble particles
- **Duty cycle and exhaust temperatures** - All catalytic exhaust aftertreatment equipment require a minimum temperature before they become effective. DOC, pDPF and CRT type DPF require temperatures above approximately 250° to be effective in reducing DPM, while CDPF require temperatures of approximately 350° C. Lower temperatures reduce the effectiveness of DOC and pDPF but do not cause an impact on the operation of the engine, whereas sufficient exhaust gas temperatures are critical for DPF to avoid excessive soot accumulation and increase in exhaust back pressure. Exhaust gas temperature monitoring and data logging should be conducted under normal operating conditions to ensure effective PM reductions will be achieved
- **Diesel fuel** - Diesel fuel with the lowest possible sulfur content should be used. Diesel that complies with a sulfur content of less than 10 ppm (prescribed by the national fuel quality standards in Australia) is suitable for all diesel exhaust aftertreatment equipment and will maximise the emission control effectiveness
- **Maintenance** - DOC and pDPF are effectively maintenance free, while DPF require periodic cleaning. Refer to Section 6.1.3.6 for further details about factors influencing DPF cleaning intervals.
- **Cost effectiveness** - Based on typical pricing and assumed PM reduction efficiencies of 25%, 40% and 95% for DOC, pDPF and DPF respectively. DPF are typically the most cost effective option due to their very high PM reduction efficiency, followed by DOC due to their relatively low cost, with pDPF being the least cost effective
- **Gaseous emissions** - In addition to the reduction of PM emissions, all diesel exhaust aftertreatment equipment described in this report are very effective in reducing CO and HC emissions, including air toxic compounds
- **Nitrogen dioxide** - All catalytic diesel exhaust aftertreatment equipment for reduction of PM increase the level of NO_2 to some degree. This may be an occupational health and safety (OH&S) concern in enclosed work areas, such as underground coal mines. While the catalyst increases NO_2 emissions, total NO_x emissions are unchanged.

Refer to Section 6.1.3.7 for further details when planning to retrofit DPF.

6.1.5 Exhaust emission control effectiveness

The emission reduction effectiveness for the range of diesel exhaust aftertreatment equipment available for heavy duty diesel retrofit are summarised in Table 6-1.

Table 6-1: Summary of exhaust aftertreatment emission control effectiveness

Exhaust Aftertreatment Equipment	PM Reduction Range	PM Reduction assumed in Cost Benefit Analysis	Typical Exhaust Temperature Requirement (°C / % of time)	CO Reduction	HC Reduction
Diesel Oxidation Catalyst (DOC)*	15-30%	25%	>250 °C/Not applicable	50-90%	40-90%
Partial Diesel Particulate Filter (pDPF)#	30-50%	40%	>250 °C/40%	70-90%	60-80%

Exhaust Aftertreatment Equipment	**PM Reduction Range**	**PM Reduction assumed in Cost Benefit Analysis**	**Typical Exhaust Temperature Requirement (°C / % of time)**	**CO Reduction**	**HC Reduction**
Catalysed Diesel Particulate Filter (CDPF)^	>90%	90%	>350 °C/30% >280 °C/50%	80-95%	70-95%
Oxidation Catalyst plus Diesel Particulate Filter (CRT type DPF)^	>90%	90%	>250 °C/40%	80-95%	70-95%
References *Refer to Section 6.1.1 for further details #Refer to Section 6.1.2 for further details ^Refer to Section 6.1.3 for further details					

6.2 Development and Manufacturing Companies

This section provides a summary of companies that develop and manufacture exhaust aftertreatment equipment for non-road diesels.

6.2.1 BASF Australia Ltd

BASF acquired Engelhard Corporation in 2006. Engelhard pioneered the development of emission control catalysts in the 1970s and was a leading developer and supplier of petrol and diesel exhaust catalysts to OEMs and the retrofit market.

BASF Catalyst division is a part of the German BASF SE group. Mobile exhaust emission products include:

- Diesel Oxidation Catalysts (DOC)
- Catalysed Soot Filters (DPF)
- Selective Catalytic Reduction (SCR) catalyst systems for NO_x reduction
- Ammonia oxidation catalysts
- Lean NO_x Traps
- Petrol engine Three-Way Catalysts.

More information is available at http://www.catalystsinfo.com/

6.2.2 Johnson Matthey (Aust) Ltd

Johnson Matthey have been developing and supplying exhaust catalysts to the OEM and retrofit market for more than 40 years. They pioneered the use of NO_2 as a soot oxidant in the Continuously Regenerating Trap CRT™ DPF in the 1990s.

Mobile exhaust emission products include:

- Diesel Oxidation Catalysts (DOC)
- Diesel Particulate Filters (CRT™, CCRT™, AdvCRT™)
- Selective Catalytic Reduction (SCR) catalyst systems for NO_x reduction
- NO_x adsorber catalysts
- Petrol engine Three-Way Catalysts.

More information is available at http://ect.jmcatalysts.com/index.asp

6.2.3 Umicore Automotive Catalysts

Umicore is a global metals and materials group who entered the automotive catalyst market in 2003 when they purchased the Degussa precious metals group from OMG. They later purchased the automotive catalysts business of Delphi AC. They supply exhaust catalysts to the OEM and retrofit markets and are one of the top three OEM suppliers worldwide (with BASF and Johnson Matthey).

In Australia, Umicore supply the Australian automotive manufacturing industry with automotive catalysts. Mobile exhaust emission products include:

- Diesel Oxidation Catalysts (DOC)
- Catalysed Diesel Particulate Filters (CDPF)
- Lean-NOx Traps (LNT)
- Selective Catalytic Reduction (SCR) Systems
- Ammonia Slip Catalysts (ASC)
- HC-based NOx Control (HC-DeNOx)
- Petrol engine Three-Way Catalysts.

More information is available at http://www.automotivecatalysts.umicore.com/en/Home/

6.2.4 CDTi

CDTi is a US based developer and manufacturer of exhaust emission catalysts for the OEM and retrofit market.

Mobile exhaust emission products include:

- Diesel Oxidation Catalysts (DOC)
- Catalysed Diesel Particulate Filters (CDPF) including passive and active (electrically heated) and fuel borne catalyst
- Selective Catalytic Reduction (SCR) Systems
- Petrol engine Three-Way Catalysts.

More information is available at http://www.cdti.com/content/americas/about/overview.htm

6.3 Installation and Retrofit Businesses

This section provides a summary of companies that supply and install retrofit exhaust aftertreatment equipment for non-road diesels.

6.3.1 Exhaust Control Industries

Exhaust Control Industries is a Melbourne based company specialising in control of air and noise pollution from industrial premises and industrial equipment. They supply and install the following products for diesel equipment:

- Diesel Oxidation Catalysts (DOC)
- Partial Diesel Particulate Filters (pDPF)
- Catalysed Diesel Particulate Filters (CDPF)
- Selective Catalytic Reduction (SCR) Systems.

More information is available at http://www.exhaustcontrol.com.au/default.aspx

6.3.2 IAC Colpro Pty Ltd

IAC Colpro is the Australia division of the international IAC Acoustics. IAC specialise in industrial acoustic attenuation solutions and exhaust aftertreatment. They supply and install the following products for diesel equipment:

- Diesel Oxidation Catalysts (DOC)
- Partial Diesel Particulate Filters (pDPF)
- Catalysed Diesel Particulate Filters (CDPF)
- Selective Catalytic Reduction (SCR) Systems.

More information is available at http://www.iac-acoustics.com/au/

6.3.3 MEIGroup Pty Ltd

Mammoth Equipment & Exhausts is a Perth based company specialising in supply of thermal lagging and exhaust equipment products to the mining industry. They supply and install the following products for diesel equipment:

- Diesel Oxidation Catalysts (DOC)
- Partial Diesel Particulate Filters (pDPF)
- Catalysed Diesel Particulate Filters (CDPF)
- Selective Catalytic Reduction (SCR) Systems.

Contact information is available at http://www.mammothequip.com.au/

6.3.4 Parratech Environmental Control

Parratech Environmental Control specialises in Acoustic, Emission & Energy Solutions for the Power Generation, Industrial & Mining markets. They supply and install the following products for diesel equipment:

- Diesel Oxidation Catalysts (DOC)
- Partial Diesel Particulate Filters (pDPF)
- Catalysed Diesel Particulate Filters (CDPF)
- Selective Catalytic Reduction (SCR) Systems.

More information is available at http://www.parratech.com.au/

6.3.5 Aletek

Aletek specialise in the supply of heavy duty exhaust systems including exhaust aftertreatment equipment. They supply and install the following products for diesel equipment:

- Diesel Oxidation Catalysts (DOC)
- Partial Diesel Particulate Filters (pDPF)
- Catalysed Diesel Particulate Filters (CDPF)
- Selective Catalytic Reduction (SCR) Systems.

More information is available at http://www.aletek.com.au/

6.3.6 Umicore Marketing Services Australia

Umicore Australia is a division of Umicore Automotive Catalysts and supply catalysts to the Australia automotive manufacturing industry. They are able to supply:

- Diesel Oxidation Catalysts (DOC)
- Catalysed Diesel Particulate Filters (CDPF)
- Lean-NOx Traps (LNT)
- Selective Catalytic Reduction (SCR) Systems
- Ammonia Slip Catalysts (ASC)
- HC-based NOx Control (HC-DeNOx).

More information on Umicore products is available at http://www.automotivecatalysts.umicore.com/en/Home/ and Australian contacts at http://www.automotivecatalysts.umicore.com/en/autoCatsWebcontacts/

6.4 Exhaust Aftertreatment Equipment Capital Costs

NSW coal mine non-road diesel equipment fleet data from the survey of EPA-licensed coal mines (EPA, 2013b) (including equipment type/make/model and engine make/model/power rating) was provided to exhaust aftertreatment equipment retrofit suppliers, who used the information to estimate costs for the supply and installation of DOC, pDPF and DPF. Exhaust Control Industries, IAC Colpro, Mammoth Equipment & Exhausts, Johnson Matthey and Umicore provided retrofit diesel exhaust aftertreatment equipment information and cost data for the range of non-road diesel equipment used at NSW coal mines.

All DPF costs include the supply and installation of an exhaust back pressure monitoring system. The DPF costs provided are based on a retrofit industry standard maximum exhaust back pressure limit of 10 kPa for engines greater than 500 kW as specified in the European Verification of Emission Reduction Technologies (VERT) scheme (DieselNet, 2007 & VERT, 2014).

The costs provided are summarised in Figure 6-8, Figure 6-9 and Figure 6-10 as a function of engine power in kilowatts (kW). Installation costs will vary significantly depending on installation space and access constraints.

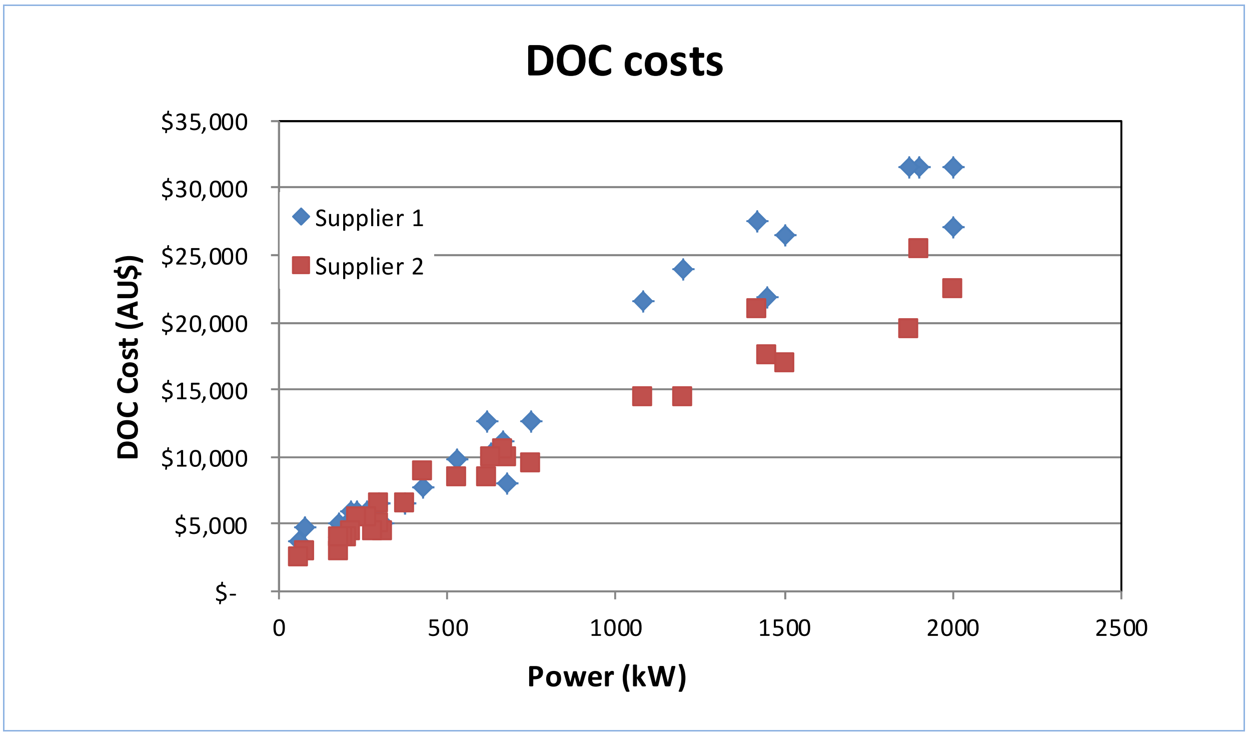


Figure 6-8: DOC cost vs. engine power (2013 AUD)

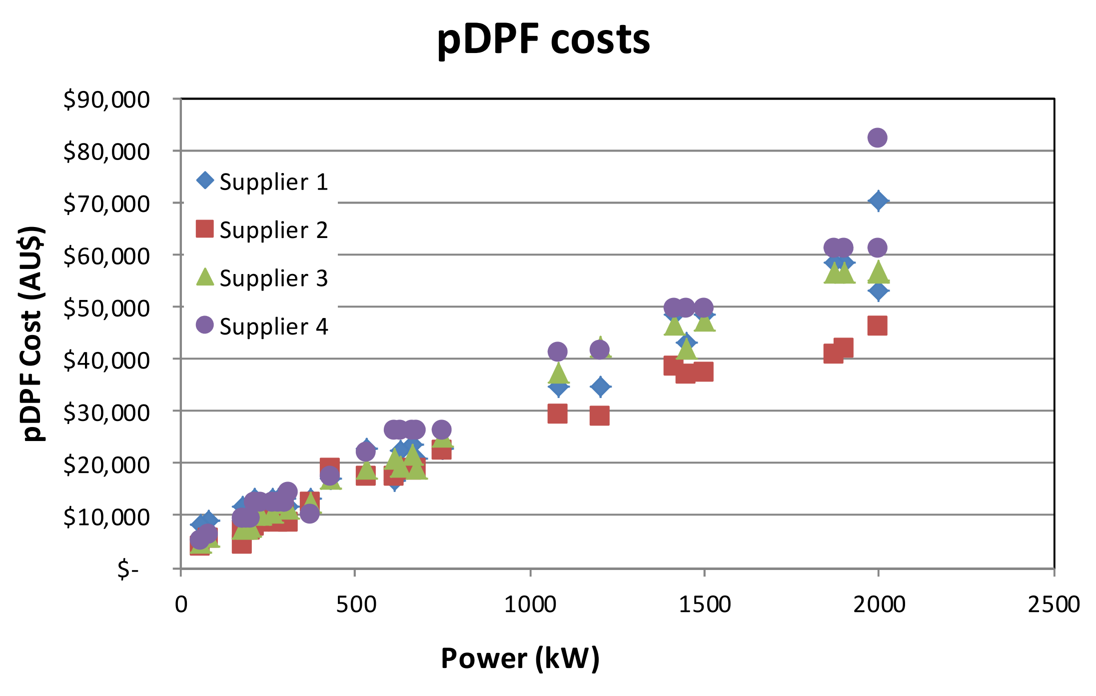


Figure 6-9: Partial DPF cost vs. engine power (2013 AUD)

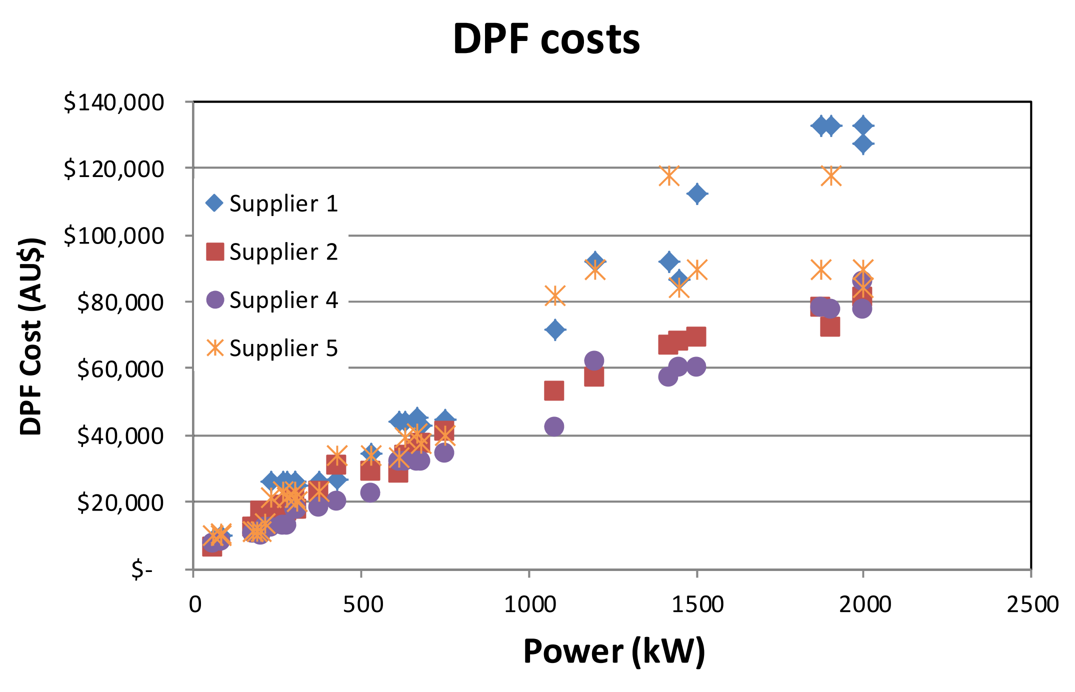


Figure 6-10: Catalysed DPF/Ox.Cat+DPF cost vs. engine power (2013 AUD)

The average costs of the various retrofit exhaust aftertreatment equipment technologies provided by all suppliers as a function of engine power in Horsepower (Hp) are shown in Figure 6-11. Note the engine power is in Hp as the linear regressions were used to estimate equipment costs that are consistent with the imperial units used in the USEPA *NONROAD2008a Model* (USEPA, 2009b) methodology.

For passive DPFs, the two lowest costs shown in Figure 6-10 were averaged since they were provided by experienced companies operating in Australia and are quite consistent with each other. For active

DPFs, only one supplier provided costs. The incremental cost from the supplier of active DPFs relative to their passive DPFs was added to the average passive DPF price. Linear regressions were used to develop formulae, which express the costs as a function of engine power. The linear regressions are shown in Figure 6-11 and the equation variables are presented in Table 6-2.

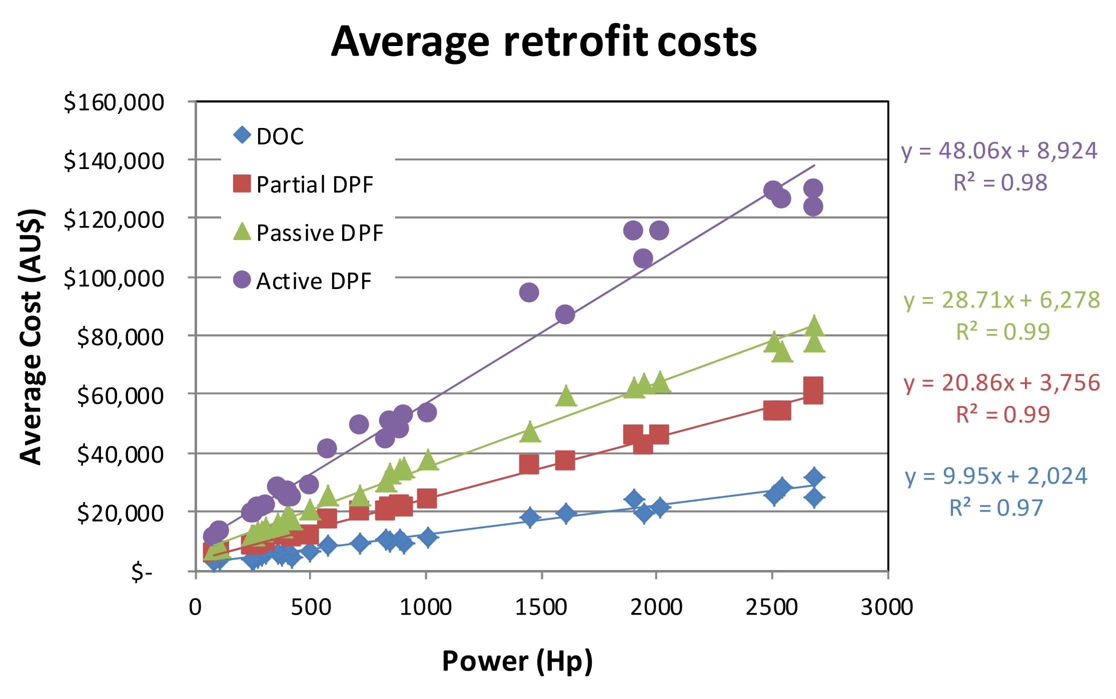


Figure 6-11: Average cost of retrofit exhaust aftertreatment equipment (2013 AUD) – linear regression

Table 6-2: Average cost of retrofit exhaust aftertreatment equipment (2013 AUD) - formulae

Exhaust Aftertreatment Equipment	Cost* = m x Hp + b		
	m	b	R^2
Diesel Oxidation Catalyst (DOC)	9.95	2,024	0.97
Partial Diesel Particulate Filter (pDPF)	20.86	3,756	0.99
Passive Diesel Particulate Filter (DPF)	28.71	6,278	0.99
Active Diesel Particulate Filter (DPF)	48.06	8,924	0.98
*An inflation rate of 2.4% (ABS, 2013b) has been used to convert from 2013 AUD to 2012 AUD			

6.5 Exhaust Aftertreatment Equipment Maintenance Costs

In retrofit exhaust aftertreatment equipment applications, incremental maintenance costs are largely incurred when cleaning DPF (refer to Section 6.1.3 for further details), while DOC (refer to Section 6.1.1 for further details) and pDPF (refer to Section 6.1.2 for further details) are essentially maintenance free.

Diesel particulate filter cleaning intervals and costs primarily depend on oil consumption, average engine load and DPF size. Assuming normal oil consumption and DPF size, the cleaning cost can be conveniently expressed as a percentage of the diesel use or diesel cost, which accounts for the average engine load.

Diesel particulate filter cleaning costs from the USEPA Tier 4 Final Regulatory Analysis have been used. These incremental annual maintenance costs are expressed as percentages of diesel cost and are presented in Table 6-3 (USEPA, 2004).

Table 6-3: Maintenance costs for DPF

Horsepower (Hp)	DPF maintenance costs expressed as % diesel cost
< 25 Hp	0.00
25 ≤ Hp < 50	3.43
50 ≤ Hp < 75	2.39
75 ≤ Hp < 175	1.19
175 ≤ Hp < 300	0.30
300 ≤ Hp < 600	0.15
600 ≤ Hp < 750	0.15
≥ 750 Hp	0.30

The USEPA DPF maintenance cost estimates presented in Table 6-3 have been compared to estimates made from engine OEM specified DPF cleaning interval specifications.

Caterpillar specifies a minimum ash cleaning interval on their US Tier 4 compliant C15 industrial non-road diesel engine of 500,000 km or 5,000 hours for the US EPA07 compliant C15 on-road diesel engine. Cummins specifies a DPF cleaning interval of up to 300,000 to 500,000 km, 250,000 litres of fuel or 4,500 hours for their ADR80/03 certified ISX15 on-road diesel engine.

Cleaning intervals for high power diesel engines (≥ 560 kW) used at NSW open-cut coal mines will vary from these examples according to their relative oil consumption, average engine load and DPF size. Mining haul trucks have about 30% higher load factor and are likely to have similar or slightly higher oil consumption relative to fuel consumption when compared to typical on-road trucks which have oil consumption of around 0.05-0.08% of fuel consumption. The Caterpillar 3516B used in generator applications has an oil consumption specification of 0.08%. High power coal mine haul trucks are therefore estimated to have a cleaning interval of about 3,000 to 4,500 hours or 8 to 13 months (oil consumption ~0.1% of fuel consumption). High oil consumption engines (>0.2%) will have proportionally shorter cleaning intervals. At a cost of $250 per element to clean filters on an exchange basis, for a 2700 kW haul truck with 22 DPF elements (sized for 2 kPa clean exhaust back pressure), the DPF maintenance cost would be 22 x $250 x 0.9 to 1.5 = $4,950 to $8,250 per year. Fuel use is estimated at about 1,500 kilolitres/year or $1.70 million, so the DPF maintenance cost is of order 0.3% to 0.5% of diesel cost. The CBA uses a DPF maintenance cost of 0.3% of diesel cost for high power (≥ 560 kW) engines, so a sensitivity analysis of 0.5% of diesel cost has been carried out (refer to Section 8.5 for further details).

6.6 Exhaust Aftertreatment Equipment Operating Costs

In retrofit exhaust aftertreatment equipment applications, incremental operating costs are incurred when using active DPF generation (refer to Section 6.1.3 for further details), while DOC (refer to Section 6.1.1 for further details) and pDPF (refer to Section 6.1.2 for further details) have no additional operating costs.

When operating conditions maintain sufficient exhaust temperatures, the DPF is continually self-regenerating and this is known as passive regeneration. On very infrequent occasions, an active self-regeneration is required to remove a build-up of PM in the DPF, due to insufficient exhaust temperatures. Field tests show that active DPF regenerations are less than about 1% of the equipment operating time. Under most normal operating conditions, the overall fuel consumption increase due to active DPF regeneration is barely measurable or approximately 0.1% for most applications. Additional diesel consumption of 0.1% is quoted by original equipment manufacturers (OEM) when using DPF and this is presented for relevant engine horsepower ranges in Table 6-4.

Table 6-4: Operating costs for DPF

Horsepower (Hp)	DPF operating costs expressed as % diesel cost*
< 25 Hp	0.0
25 ≤ Hp < 50	0.1
50 ≤ Hp < 75	0.1
75 ≤ Hp < 175	0.1
175 ≤ Hp < 300	0.1
300 ≤ Hp < 600	0.1
600 ≤ Hp < 750	0.1
≥ 750 Hp	0.1
*References http://cumminsengines.com/cummins-particulate-filter	

7 NON-ROAD DIESEL ENGINE EMISSION SURVEY OF NSW COAL MINES

This section describes the survey of EPA-licensed coal mines and provides a detailed summary of the survey findings.

7.1 Survey of EPA-Licensed Coal Mines

The aim of this project is to complete a cost benefit analysis (CBA), which evaluates a number of options for reducing exhaust emissions from non-road diesel vehicles and equipment (non-road diesels), including:

- retrofitting in-service equipment with particulate matter (PM) exhaust aftertreatment technologies
- procuring replacement equipment that is compliant with EU (European Commission, 2013) and/or US (USEPA, 2013a) emission standards, and/or
- adopting ultra-low sulfur diesel (10 ppm sulfur) (Attorney-General's Department, 2009a), for all 64 coal mines in NSW that hold a current environment protection licence (EPL) (EPA, 2013a).

A survey of EPA-licensed coal mines (EPA, 2013b) was carried out to provide the detailed supporting technical data required to complete a CBA and objectively establish whether there are technically and economically feasible options available to reduce non-road diesel emissions.

The EPA briefed the NSW Minerals Council (NSW MC) and members about the proposed EPA survey on 29 January 2013. The NSW MC coordinated industry consultation with BHP Billiton, Peabody, Rio Tinto and Xstrata on the draft EPA survey between 6 February and 19 March 2013. EPA officers met with Xstrata fleet management staff at Bulga mine on 8 March 2013 to bench test the draft EPA survey. The draft EPA survey was modified in line with comments received during industry consultation.

The EPA survey was issued to 64 EPA-licensed coal mines on 11 April 2013 under the *Protection of the Environment Operations Act 1997* (POEO Act) (PCO, 2010) using a Section 191 Notice to Provide Information and/or Records and ended on 24 May 2013.

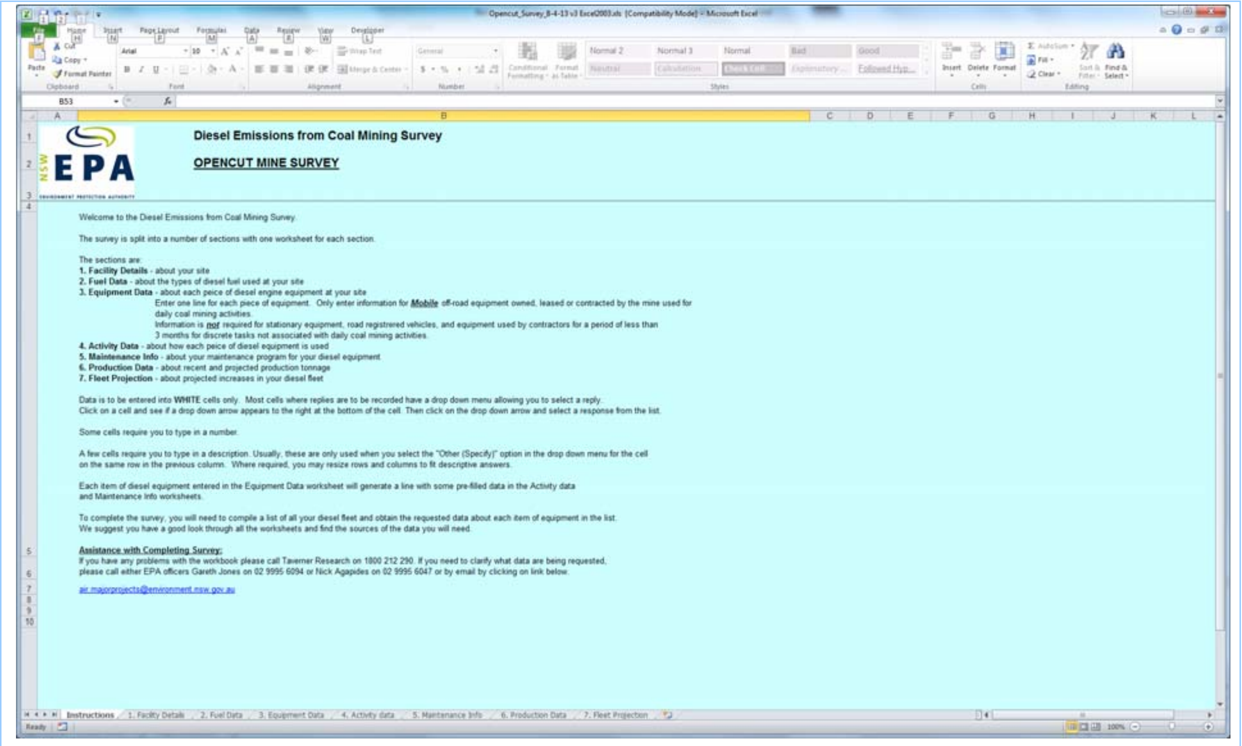
While EPA-licensees were given 6 weeks to complete and submit the survey, the EPA granted two extensions to the original deadline (i.e. 7 June 2013 and 14 June 2013, respectively). The EPA granted six exemptions from participating in the survey, considering these coal mines have little or no non-road diesels activity because they are either closed with rehabilitation complete or in care and maintenance with no foreseeable plans to commence production.

A 100% response rate to the survey was achieved with high quality data completed and submitted by the 58 operating EPA-licensed coal mines in NSW.

Two Microsoft® Excel™ workbooks have been developed for the survey, one for open-cut and the other for underground coal mines. The open-cut coal mines workbook seeks more comprehensive information, since the main focus of this project is about non-road diesels used at open-cut rather than underground coal mines (except for surface equipment). Since non-road diesels at underground coal mines are regulated by the Division of Resources and Energy (DRE) under the *Coal Mine Health and Safety Act 2002* (CMHS Act) (PCO, 2013b) (refer to Section 4.3 for further details), reducing emissions from non-road diesels used in underground applications are not within the scope of this project. The open-cut and underground coal mines workbooks contain the information shown in Table 7-1.

Table 7-1: EPA-licensed coal mine survey workbook contents

Content	Open-cut coal mines	Underground coal mines
Instructions – Detailed instructions about the survey and navigating through the workbook (Figure 7-1)	✓	✓
Facility details – Details about the EPA-licensed premises, person completing the survey and the reporting period (Figure 7-2)	✓	✓
Fuel data – Type, quantity, sulfur content, supplier and price of diesel consumed (Figure 7-3)	✓	✓
Equipment data – Type, make, model, age, engine power, emissions certification, fuel consumption, load factors, engine life and equipment life for each non-road diesel vehicle and equipment (Figure 7-4)	✓	✓
Activity data – Coal mine operating months and days and operating hours for each non-road diesel vehicle and equipment (Figure 7-5)	✓	✓
Maintenance information - Details about engine maintenance systems, engine rebuild and equipment replacement strategies (Figure 7-6)	✓	✗
Production data – Run-of-Mine (ROM) coal production (open-cut and underground) and overburden handled (open-cut) for the reporting period and future years (Figure 7-7)	✓	✓
Fleet projection - Type, make, model, engine power, emissions certification for each future non-road diesel vehicle and equipment (Figure 7-8)	✓	✗



Diesel Emissions from Coal Mining Survey

OPENCUT MINE SURVEY

Welcome to the Diesel Emissions from Coal Mining Survey.

The survey is split into a number of sections with one worksheet for each section.

The sections are:
1. **Facility Details** - about your site
2. **Fuel Data** - about the types of diesel fuel used at your site
3. **Equipment Data** - about each peice of diesel engine equipment at your site
    Enter one line for each piece of equipment. Only enter information for **Mobile** off-road equipment owned, leased or contracted by the mine used for daily coal mining activities.
    Information is **not** required for stationary equipment, road registrered vehicles, and equipment used by contractors for a period of less than 3 months for discrete tasks not associated with daily coal mining activities.
4. **Activity Data** - about how each peice of diesel equipment is used
5. **Maintenance Info** - about your maintenance program for your diesel equipment
6. **Production Data** - about recent and projected production tonnage
7. **Fleet Projection** - about projected increases in your diesel fleet

Data is to be entered into **WHITE** cells only. Most cells where replies are to be recorded have a drop down menu allowing you to select a reply.
Click on a cell and see if a drop down arrow appears to the right at the bottom of the cell. Then click on the drop down arrow and select a response from the list.

Some cells require you to type in a number.

A few cells require you to type in a description. Usually, these are only used when you select the "Other (Specify)" option in the drop down menu for the cell on the same row in the previous column. Where required, you may resize rows and columns to fit descriptive answers.

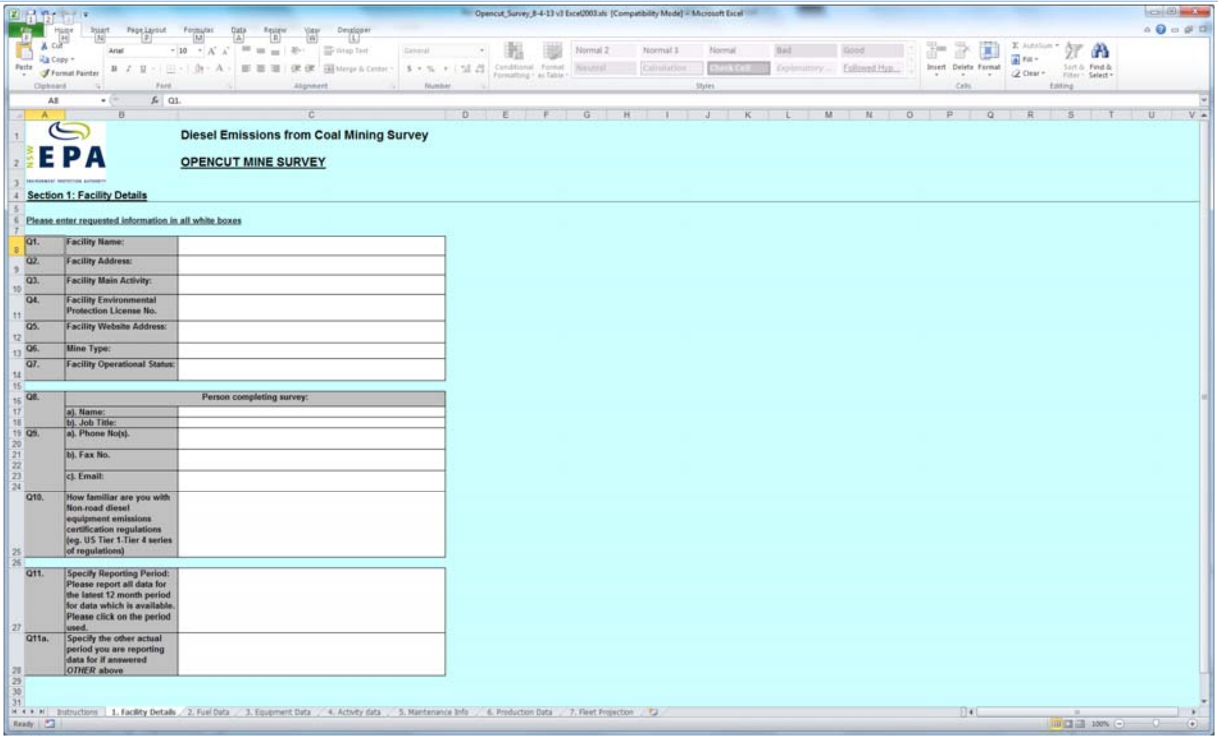
Each item of diesel equipment entered in the Equipment Data worksheet will generate a line with some pre-filled data in the Activity data and Maintenance Info worksheets.

To complete the survey, you will need to compile a list of all your diesel fleet and obtain the requested data about each item of equipment in the list.
We suggest you have a good look through all the worksheets and find the sources of the data you will need.

Assistance with Completing Survey:
If you have any problems with the workbook please call Taverner Research on 1800 212 290. If you need to clarify what data are being requested, please call either EPA officers Gareth Jones on 02 9995 6094 or Nick Agapides on 02 9995 6047 or by email by clicking on link below.

air.majorprojects@environment.nsw.gov.au

Figure 7-1: EPA-licensed coal mine survey workbook - instructions



Diesel Emissions from Coal Mining Survey

OPENCUT MINE SURVEY

Section 1: Facility Details

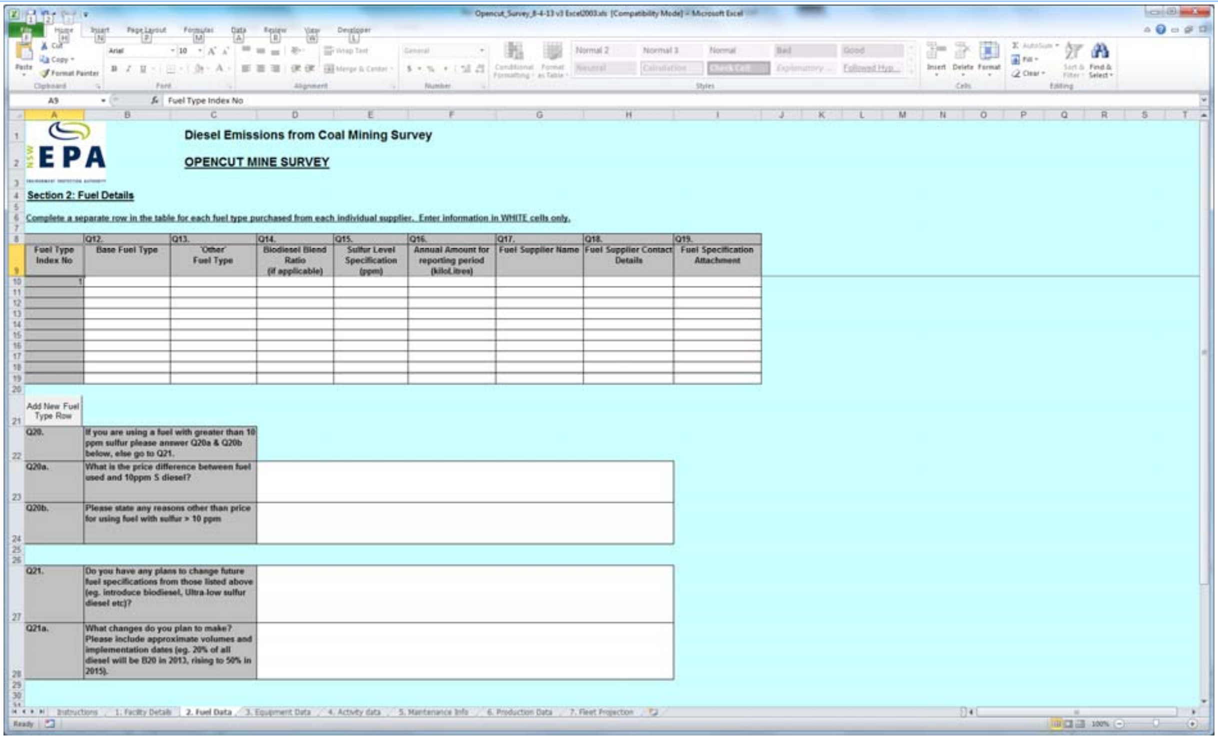
Please enter requested information in all white boxes

Q1.	Facility Name:	
Q2.	Facility Address:	
Q3.	Facility Main Activity:	
Q4.	Facility Environmental Protection License No.	
Q5.	Facility Website Address:	
Q6.	Mine Type:	
Q7.	Facility Operational Status:	

Q8.	Person completing survey:	
	a). Name:	
	b). Job Title:	
Q9.	a). Phone No(s).	
	b). Fax No.	
	c). Email:	
Q10.	How familiar are you with Non-road diesel equipment emissions certification regulations (eg. US Tier 1-Tier 4 series of regulations)	

Q11.	Specify Reporting Period: Please report all data for the latest 12 month period for data which is available. Please click on the period used.	
Q11a.	Specify the other actual period you are reporting data for if answered *OTHER* above	

Figure 7-2: EPA-licensed coal mine survey workbook – facility details



Diesel Emissions from Coal Mining Survey

OPENCUT MINE SURVEY

Section 2: Fuel Details

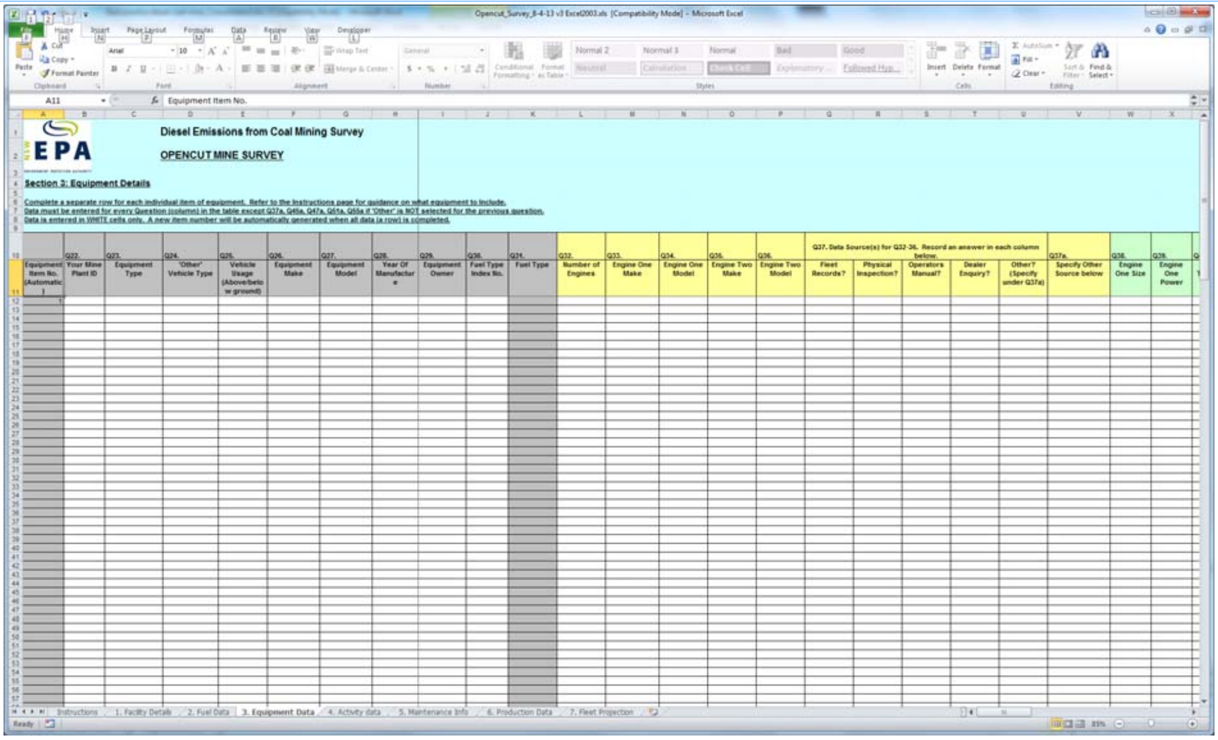
Complete a separate row in the table for each fuel type purchased from each individual supplier. Enter information in WHITE cells only.

	Q12.	Q13.	Q14.	Q15.	Q16.	Q17.	Q18.	Q19.
Fuel Type Index No	Base Fuel Type	'Other' Fuel Type	Biodiesel Blend Ratio (if applicable)	Sulfur Level Specification (ppm)	Annual Amount for reporting period (kiloLitres)	Fuel Supplier Name	Fuel Supplier Contact Details	Fuel Specification Attachment
1								

Q20.	If you are using a fuel with greater than 10 ppm sulfur please answer Q20a & Q20b below, else go to Q21.	
Q20a.	What is the price difference between fuel used and 10ppm S diesel?	
Q20b.	Please state any reasons other than price for using fuel with sulfur > 10 ppm	

Q21.	Do you have any plans to change future fuel specifications from those listed above (eg. introduce biodiesel, Ultra-low sulfur diesel etc)?	
Q21a.	What changes do you plan to make? Please include approximate volumes and implementation dates (eg. 20% of all diesel will be B20 in 2013, rising to 50% in 2015).	

Figure 7-3: EPA-licensed coal mine survey workbook – fuel data



Equipment Item No.

Diesel Emissions from Coal Mining Survey

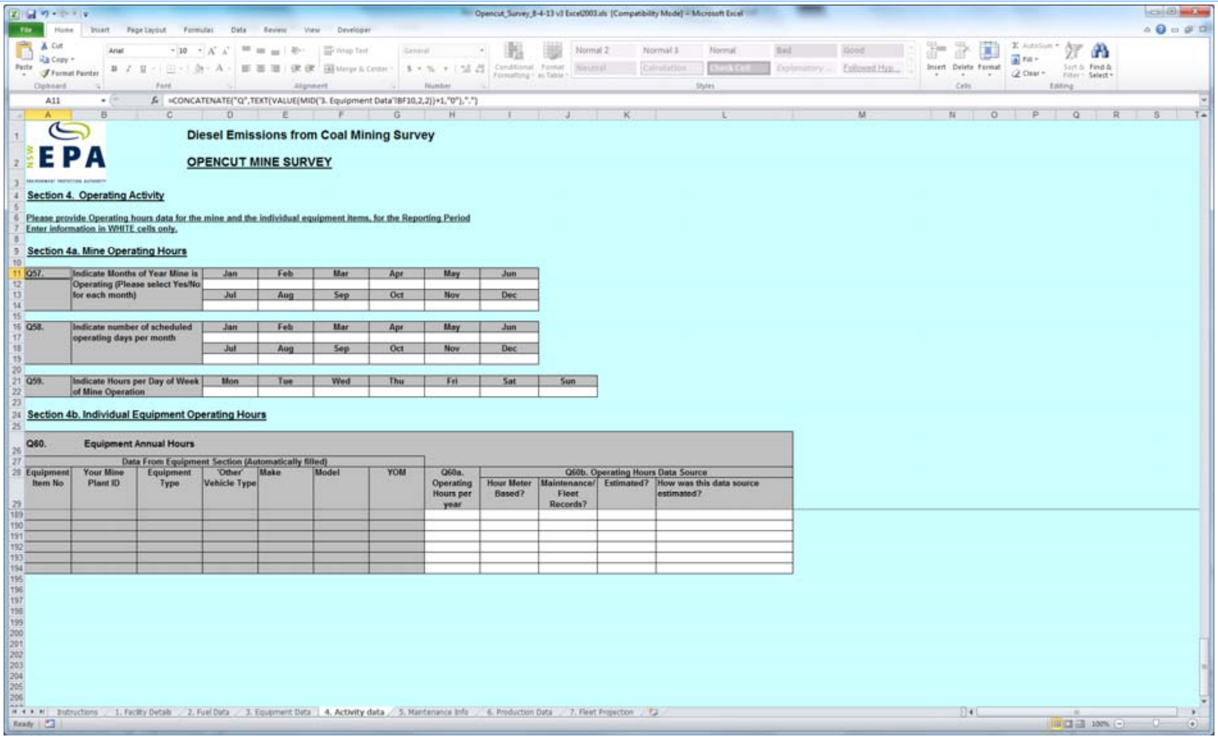
OPENCUT MINE SURVEY

Section 3: Equipment Details

Complete a separate row for each individual item of equipment. Refer to the Instructions page for guidance on what equipment to include.
Data must be entered for every Question (column) in the table except Q37a, Q46a, Q47a, Q51a, Q55a if 'Other' is NOT selected for the previous question.
Data is entered in WHITE cells only. A new item number will be automatically generated when all data (a row) is completed.

	Q22.	Q23.	Q24.	Q25.	Q26.	Q27.	Q28.	Q29.	Q30.	Q31.	Q32.	Q33.	Q34.	Q35.	Q36.	Q37. Data Source(s) for Q32-36. Record an answer in each column below.					Q37a.	Q38.	Q39.
Equipment Item No. (Automatic)	Your Mine Plant ID	Equipment Type	'Other' Vehicle Type	Vehicle Usage (Above/below ground)	Equipment Make	Equipment Model	Year Of Manufacture	Equipment Owner	Fuel Type Index No.	Fuel Type	Number of Engines	Engine One Make	Engine One Model	Engine Two Make	Engine Two Model	Fleet Records?	Physical Inspection?	Operators Manual?	Dealer Enquiry?	Other? (Specify under Q37a)	Specify Other Source below	Engine One Size	Engine One Power
1																							

Figure 7-4: EPA-licensed coal mine survey workbook – equipment data



=CONCATENATE("Q",TEXT(VALUE(MID('3. Equipment Data'!BF10,2,2))+1,"0"),".")

Diesel Emissions from Coal Mining Survey

OPENCUT MINE SURVEY

Section 4. Operating Activity

Please provide Operating hours data for the mine and the individual equipment items, for the Reporting Period
Enter information in WHITE cells only.

Section 4a. Mine Operating Hours

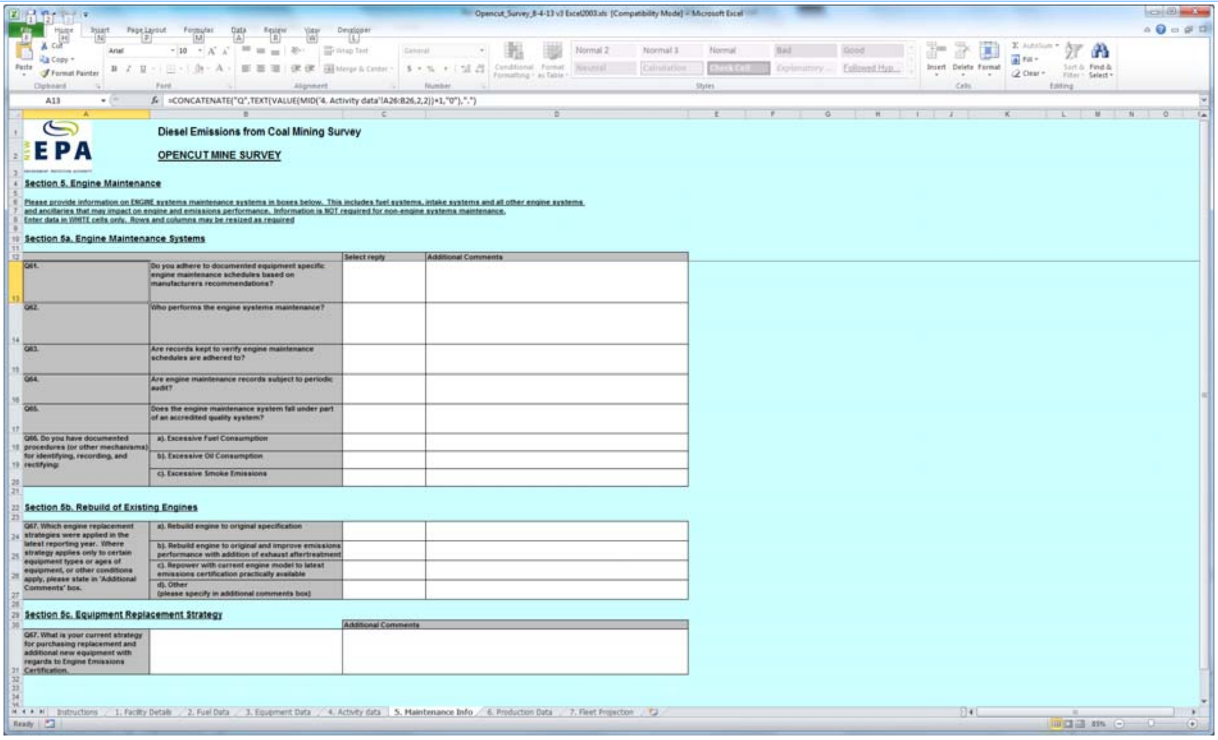
Q57.	Indicate Months of Year Mine is Operating (Please select Yes/No for each month)	Jan	Feb	Mar	Apr	May	Jun	
		Jul	Aug	Sep	Oct	Nov	Dec	
Q58.	Indicate number of scheduled operating days per month	Jan	Feb	Mar	Apr	May	Jun	
		Jul	Aug	Sep	Oct	Nov	Dec	
Q59.	Indicate Hours per Day of Week of Mine Operation	Mon	Tue	Wed	Thu	Fri	Sat	Sun

Section 4b. Individual Equipment Operating Hours

Q60. Equipment Annual Hours

Data From Equipment Section (Automatically filled)								Q60b. Operating Hours Data Source			
Equipment Item No	Your Mine Plant ID	Equipment Type	'Other' Vehicle Type	Make	Model	YOM	Q60a. Operating Hours per year	Hour Meter Based?	Maintenance/ Fleet Records?	Estimated?	How was this data source estimated?

Figure 7-5: EPA-licensed coal mine survey workbook – activity data



A13 =CONCATENATE("Q",TEXT(VALUE(MID('4. Activity data'!A26:B26,2,2))+1,"0"),".")

Diesel Emissions from Coal Mining Survey

OPENCUT MINE SURVEY

Section 5. Engine Maintenance

Please provide information on ENGINE systems maintenance systems in boxes below. This includes fuel systems, intake systems and all other engine systems and ancillaries that may impact on engine and emissions performance. Information is NOT required for non-engine systems maintenance.
Enter data in WHITE cells only. Rows and columns may be resized as required

Section 5a. Engine Maintenance Systems

		Select reply	Additional Comments
Q61.	Do you adhere to documented equipment specific engine maintenance schedules based on manufacturers recommendations?		
Q62.	Who performs the engine systems maintenance?		
Q63.	Are records kept to verify engine maintenance schedules are adhered to?		
Q64.	Are engine maintenance records subject to periodic audit?		
Q65.	Does the engine maintenance system fall under part of an accredited quality system?		
Q66. Do you have documented procedures (or other mechanisms) for identifying, recording, and rectifying:	a). Excessive Fuel Consumption		
	b). Excessive Oil Consumption		
	c). Excessive Smoke Emissions		

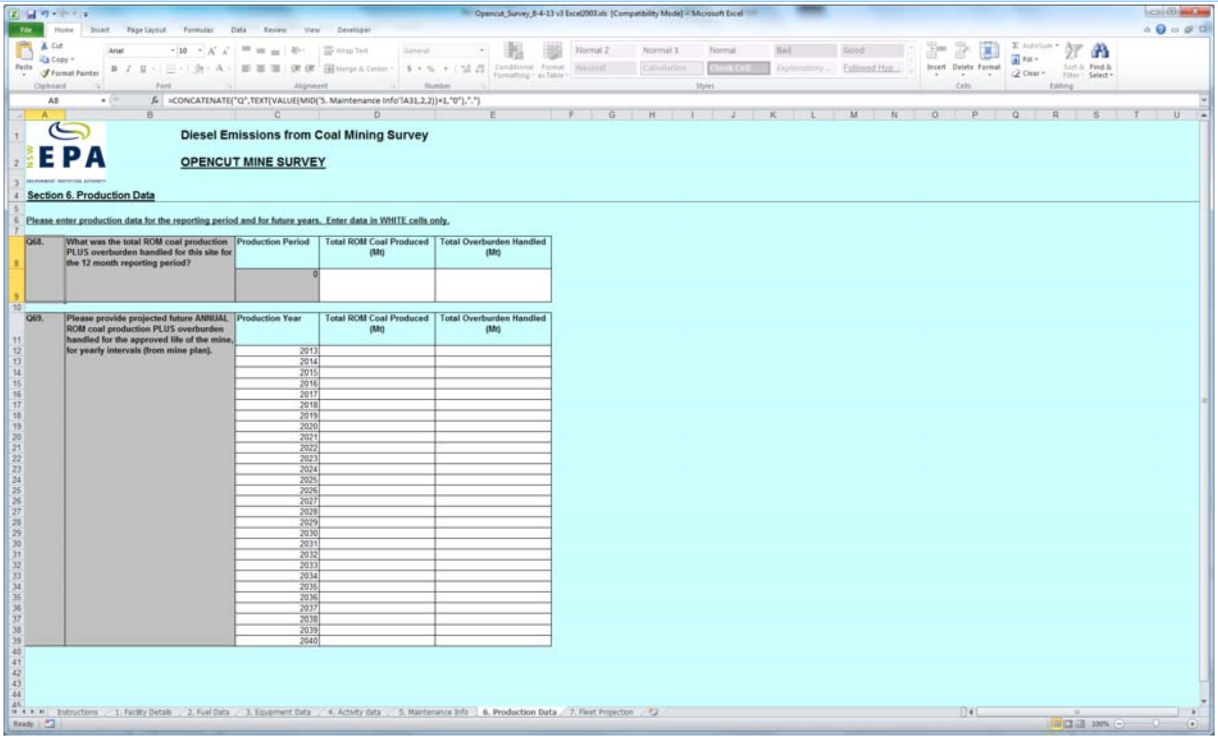
Section 5b. Rebuild of Existing Engines

Q67. Which engine replacement strategies were applied in the latest reporting year. Where strategy applies only to certain equipment types or ages of equipment, or other conditions apply, please state in 'Additional Comments' box.	a). Rebuild engine to original specification		
	b). Rebuild engine to original and improve emissions performance with addition of exhaust aftertreatment		
	c). Repower with current engine model to latest emissions certification practically available		
	d). Other (please specify in additional comments box)		

Section 5c. Equipment Replacement Strategy

		Additional Comments
Q67. What is your current strategy for purchasing replacement and additional new equipment with regards to Engine Emissions Certification.		

Figure 7-6: EPA-licensed coal mine survey workbook – maintenance information



A8 =CONCATENATE("Q",TEXT(VALUE(MID('5. Maintenance Info'!A31,2,2))+1,"0"),".")

Diesel Emissions from Coal Mining Survey

OPENCUT MINE SURVEY

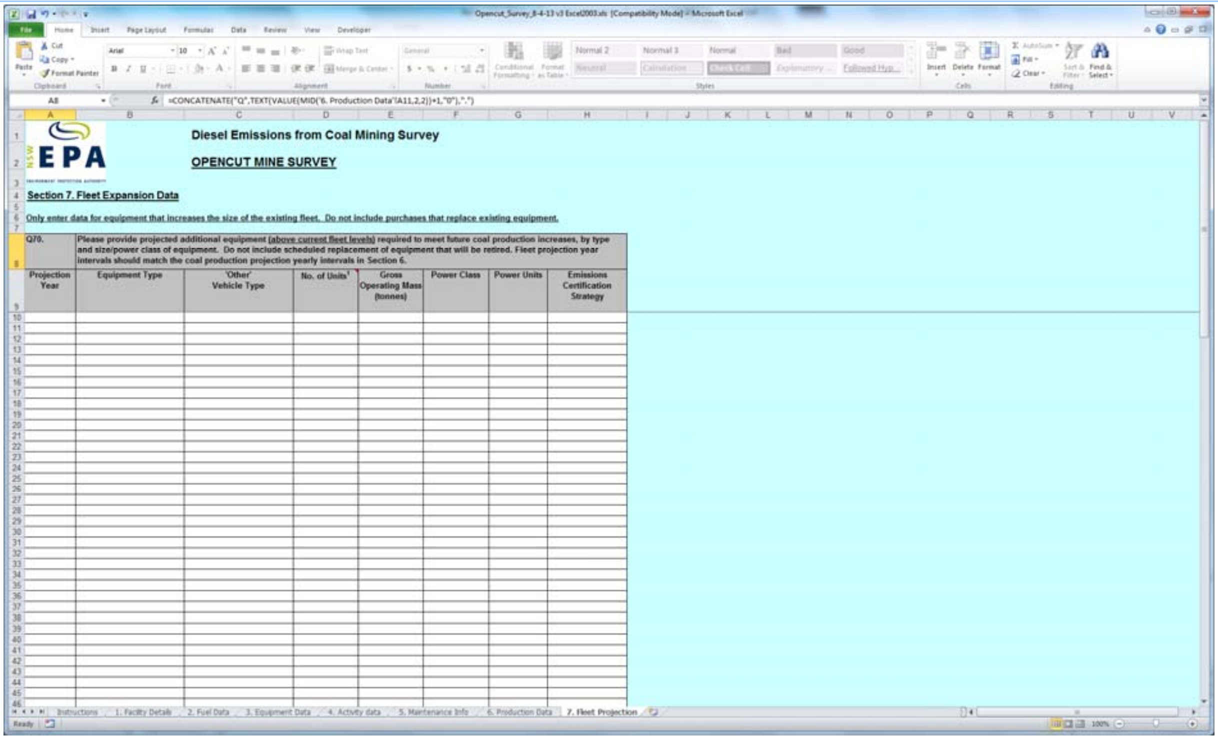
Section 6. Production Data

Please enter production data for the reporting period and for future years. Enter data in WHITE cells only.

		Production Period	Total ROM Coal Produced (Mt)	Total Overburden Handled (Mt)
Q68.	What was the total ROM coal production PLUS overburden handled for this site for the 12 month reporting period?	0		

		Production Year	Total ROM Coal Produced (Mt)	Total Overburden Handled (Mt)
Q69.	Please provide projected future ANNUAL ROM coal production PLUS overburden handled for the approved life of the mine, for yearly intervals (from mine plan).	2013		
		2014		
		2015		
		2016		
		2017		
		2018		
		2019		
		2020		
		2021		
		2022		
		2023		
		2024		
		2025		
		2026		
		2027		
		2028		
		2029		
		2030		
		2031		
		2032		
		2033		
		2034		
		2035		
		2036		
		2037		
		2038		
		2039		
		2040		

Figure 7-7: EPA-licensed coal mine survey workbook – production data



=CONCATENATE("Q",TEXT(VALUE(MID('6. Production Data'!A11,2,2))+1,"0"),".")

Diesel Emissions from Coal Mining Survey

OPENCUT MINE SURVEY

Section 7. Fleet Expansion Data

Only enter data for equipment that increases the size of the existing fleet. Do not include purchases that replace existing equipment.

Q70. **Please provide projected additional equipment (above current fleet levels) required to meet future coal production increases, by type and size/power class of equipment. Do not include scheduled replacement of equipment that will be retired. Fleet projection year intervals should match the coal production projection yearly intervals in Section 6.**

Projection Year	Equipment Type	'Other' Vehicle Type	No. of Units[1]	Gross Operating Mass (tonnes)	Power Class	Power Units	Emissions Certification Strategy

Figure 7-8: EPA-licensed coal mine survey workbook – fleet projection

7.2 Summary of Survey Results

This section provides a detailed summary of the survey findings, including facility details, fuel data, coal mine production, equipment fleet specification and activity and equipment maintenance.

7.2.1 Facility details

Facility details for all 64 coal mines in NSW that hold a current environment protection licence (EPL) (EPA, 2013a) are presented in Table 7-2 (EPA, 2013b), including the EPL number, premises name, suburb, local government area (LGA), mine type, operational status, whether surface equipment are used and if they were exempt from survey.

Table 7-2: Facility details for EPA-licensed coal mines

EPL number	Premises name	Suburb	LGA	Mine type*	Operational status	Surface equipment	Exempt from survey
191	MANNERING COLLIERY	DOYALSON	WYONG	UG	Temporarily Closed - Care & Maintenance	No	No
365	MANDALONG MINE, COORANBONG COLLIERY AND DELTA COAL SERVICES SITE	DORA CREEK	LAKE MACQUARIE	UG	Operational	Yes	No
366	MYUNA COLLIERY	WANGI WANGI	LAKE MACQUARIE	UG	Operational	Yes	No
394	ULAN COAL MINES LIMITED	MUDGEE	MID-WESTERN REGIONAL	OC & UG	Operational	Yes	No
395	NEWSTAN COLLIERY	FASSIFERN	LAKE MACQUARIE	UG	Operational	Yes	No
396	BLOOMFIELD COLLIERY	ASHTONFIELD	CESSNOCK	OC	Operational	Yes	No
416	AUSTAR COAL MINE	PELTON	CESSNOCK	UG	Operational	Yes	No
443	AWABA COLLIERY	AWABA	LAKE MACQUARIE	UG	Permanently Closed - Rehabilitation Operations Only	Yes	No
467	ANGUS PLACE COLLIERY	LIDSDALE	LITHGOW	UG	Operational	Yes	No
528	CHARBON COAL PTY LIMITED	CHARBON	MID-WESTERN REGIONAL	OC & UG	Operational	Yes	No
529	WAMBO COAL PTY LTD	WARKWORTH	SINGLETON	OC & UG	Operational	Yes	No
563	SAXONVALE COLLIERY HOLDING	SINGLETON	SINGLETON	OC	Operational	Yes	No
608	BERRIMA COLLIERY	MEDWAY	WINGECARRIBEE	UG	Operational	Yes	No
611	CORDEAUX COLLIERY	WOLLONGONG	WOLLONGONG	UG	Temporarily Closed - Care & Maintenance	No	Yes
631	IVANHOE NO.2 COLLIERY	PORTLAND	LITHGOW	OC	Permanently Closed - Rehabilitation Operations Only	No	Yes
640	HUNTER VALLEY OPERATIONS	SINGLETON	SINGLETON	OC	Operational	Yes	No
656	MUSWELLBROOK COLLIERY HOLDING	MUSWELLBROOK	MUSWELLBROOK	OC	Operational	Yes	No
726	CLARENCE COLLIERY	NEWNES JUNCTION	LITHGOW	UG	Operational	Yes	No

EPL number	Premises name	Suburb	LGA	Mine type*	Operational status	Surface equipment	Exempt from survey
765	BAAL BONE COLLIERY	LITHGOW	LITHGOW	UG	Temporarily Closed - Care & Maintenance	No	No
767	METROPOLITAN COLLIERY	HELENSBURGH	WOLLONGONG	UG	Operational	Yes	No
1087	NRE WONGAWILLI COLLIERY	WONGAWILLI	WOLLONGONG	UG	Operational	Yes	No
1095	THE INVINCIBLE COLLIERY	CULLEN BULLEN	LITHGOW	OC	Temporarily Closed - Care & Maintenance	Yes	No
1323	DRAYTON COAL MINE	MUSWELLBROOK	MUSWELLBROOK	OC	Operational	Yes	No
1360	OCEANIC COAL AUSTRALIA LIMITED	TERALBA	LAKE MACQUARIE	UG	Operational	No	No
1376	WARKWORTH COAL MINE	MOUNT THORLEY	SINGLETON	OC	Operational	Yes	No
1389	TAHMOOR COLLIERY	TAHMOOR	WOLLONDILLY	UG	Operational	Yes	No
1770	CHAIN VALLEY COLLIERY	CHAIN VALLEY BAY	WYONG	UG	Operational	Yes	No
1976	MOUNT THORLEY OPERATIONS	MOUNT THORLEY	SINGLETON	OC	Operational	Yes	No
2094	LIDDELL COAL OPERATIONS	RAVENSWORTH	MUSWELLBROOK	OC	Operational	Yes	No
2504	WEST CLIFF AND NORTH CLIFF COLLIERIES	APPIN	WOLLONDILLY	UG	Operational	Yes	No
2652	RAVENSWORTH MINING COMPLEX	RAVENSWORTH	SINGLETON	OC & UG	Operational	Yes	No
3141	UNITED COLLIERY	WARKWORTH	SINGLETON	UG	Temporarily Closed - Care & Maintenance	Yes	No
3241	DENDROBIUM MINE	MOUNT KEMBLA	WOLLONGONG	UG	Operational	Yes	No
3390	INTEGRA COAL COMPLEX	SINGLETON	SINGLETON	OC & UG	Operational	Yes	No
3391	RIX'S CREEK COLLIERY	SINGLETON	SINGLETON	OC	Operational	Yes	No
3607	SPRINGVALE COLLIERY	LIDSDALE	LITHGOW	UG	Operational	Yes	No
4460	MT OWEN COAL MINE	RAVENSWORTH	SINGLETON	OC	Operational	Yes	No
4885	DARTBROOK COAL MINE	MUSWELLBROOK	MUSWELLBROOK	UG	Temporarily Closed - Care & Maintenance	No	No
4911	PINE DALE MINE	LIDSDALE	LITHGOW	OC	Operational	Yes	No
5161	STRATFORD COAL MINE	STRATFORD	GLOUCESTER	OC	Operational	Yes	No
6538	BENGALLA MINE	MUSWELLBROOK	MUSWELLBROOK	OC	Operational	Yes	No

EPL number	Premises name	Suburb	LGA	Mine type*	Operational status	Surface equipment	Exempt from survey
10094	CANYON COAL MINE	BOGGABRI	NARRABRI	OC	Permanently Closed - Rehabilitation Operations Only	No	Yes
10341	CULLEN VALLEY MINE	CULLEN BULLEN	LITHGOW	OC	Temporarily Closed - Care & Maintenance	Yes	No
10860	RAVENSWORTH EAST MINE	RAVENSWORTH	SINGLETON	OC	Operational	Yes	No
11080	DONALDSON COAL PTY LTD	MAITLAND	MAITLAND	OC	Permanently Closed - Rehabilitation Operations Only	No	Yes
11457	MT ARTHUR COAL	MUSWELLBROOK	MUSWELLBROOK	OC	Operational	Yes	No
11701	DURALIE COAL MINE	STROUD ROAD	GREAT LAKES	OC	Operational	Yes	No
11745	BOWENS ROAD NORTH COAL PROJECT	STRATFORD	GLOUCESTER	OC	Operational	Yes	No
11879	ASHTON COAL MINE	CAMBERWELL	SINGLETON	UG	Operational	Yes	No
12040	NRE NO 1 COLLIERY	RUSSELL VALE	WOLLONGONG	UG	Operational	Yes	No
12290	WERRIS CREEK COAL	WERRIS CREEK	LIVERPOOL PLAINS	OC	Operational	Yes	No
12365	TARRAWONGA COAL MINE	BOGGABRI	NARRABRI	OC	Operational	Yes	No
12374	AIRLY MINE	CAPERTEE	LITHGOW	UG	Temporarily Closed - Care & Maintenance	Yes	No
12407	BOGGABRI COAL MINE	BOGGABRI	NARRABRI	OC	Operational	Yes	No
12425	WILPINJONG COAL PTY LTD	MUDGEE	MID-WESTERN REGIONAL	OC	Operational	Yes	No
12483	TASMAN COAL MINE	SEAHAMPTON	LAKE MACQUARIE	UG	Permanently Closed - Rehabilitation Operations Only	No	Yes
12789	NARRABRO COAL OPERATIONS	BAAN BAA	NARRABRI	UG	Operational	Yes	No
12840	GLENDELL MINE	RAVENSWORTH	SINGLETON	OC	Operational	Yes	No
12856	ABEL UNDERGROUND MINE	BLACK HILL	CESSNOCK	UG	Operational	No	No
12870	ROCGLEN COAL MINE	GUNNEDAH	GUNNEDAH	OC	Operational	Yes	No
12894	XSTRATA MANGOOLA	WYBONG	MUSWELLBROOK	OC	Operational	Yes	No

EPL number	Premises name	Suburb	LGA	Mine type*	Operational status	Surface equipment	Exempt from survey
12932	MOOLARBEN COAL MINE	MUDGEE	MID-WESTERN REGIONAL	OC	Operational	Yes	No
12957	SUNNYSIDE COAL PROJECT	GUNNEDAH	GUNNEDAH	OC	Temporarily Closed - Care & Maintenance	Yes	No
13063	IVANHOE NORTH REHABILITATION PROJECT	CULLEN BULLEN	LITHGOW	OC	Permanently Closed - Rehabilitation Operations Only	No	Yes

*OC – open-cut, UG – underground, OC & UG – combined open-cut and underground

The number of open-cut (OC), underground (UG) and combined open-cut and underground (OC & UG) coal mines in each local government area (LGA) are presented in Table 7-3 (EPA, 2013b). Thirty two coal mines are open-cut, 27 underground and five are combined open-cut and underground coal mines.

Table 7-3: EPA-licensed coal mines in each LGA

LGA	Mine type			Grand Total
	OC	UG	OC & UG	
CESSNOCK	1	2		3
GLOUCESTER	2			2
GREAT LAKES	1			1
GUNNEDAH	2			2
LAKE MACQUARIE		6		6
LITHGOW	5	5		10
LIVERPOOL PLAINS	1			1
MAITLAND	1			1
MID-WESTERN REGIONAL	2		2	4
MUSWELLBROOK	6	1		7
NARRABRI	3	1		4
SINGLETON	8	2	3	13
WINGECARRIBEE		1		1
WOLLONDILLY		2		2
WOLLONGONG		5		5
WYONG		2		2
Grand Total	**32**	**27**	**5**	**64**

The operational status of all 64 coal mines that hold a current EPL are presented in Table 7-4 (EPA, 2013b). Forty nine coal mines are operational, while 15 coal mines are either permanently (six) or temporarily (nine) closed.

Table 7-4: Operational status of EPA-licensed coal mines

Operational status	Mine type			Grand Total
	OC	UG	OC & UG	
Operational	25	19	5	49
Permanently Closed - Rehabilitation Operations Only	4	2		6
Temporarily Closed - Care & Maintenance	3	6		9

The number of coal mines that use non-road diesels in surface rather than underground applications are presented in Table 7-5 (EPA, 2013b). Fifty three coal mines use equipment in surface applications, while 11 coal mines use either underground or no non-road diesel equipment at all.

Table 7-5: Surface equipment at EPA-licensed coal mines

Surface equipment	Mine type			Grand Total
	OC	UG	OC & UG	
No	4	7		11
Yes	28	20	5	53

The number of coal mines that were exempt from the survey are presented in Table 7-6 (EPA, 2013b). Fifty eight coal mines completed the survey, while six coal mines were exempt since they are either permanently or temporarily closed and don't use non-road diesels.

Table 7-6: EPA-licensed coal mines exempt from survey

Exempt from survey	Mine type			Grand Total
	OC	UG	OC & UG	
No	28	25	5	58
Yes	4	2		6

The number of coal mines that have an awareness of US and/or EU non-road diesel regulatory requirements are presented in Table 7-7 (EPA, 2013b). Twenty eight coal mines did not respond or are not aware, 24 are somewhat familiar, while 12 are either mostly (six) or very familiar (six) with US and/or EU non-road diesel regulatory requirements.

Table 7-7: Awareness of US and/or EU non-road diesel regulatory requirements at EPA-licensed coal mines

Non-road diesel regulatory awareness	Mine type			Grand Total
	OC	UG	OC & UG	
No response	6	4		10
Not aware	9	6	3	18
Somewhat familiar	11	11	2	24
Mostly familiar	1	5		6
Very familiar	5	1		6

7.2.2 Fuel data

The annual diesel consumption for the 58 coal mines that completed the survey is presented in Table 7-8 (EPA, 2013b). This data is based on reported coal mine premises-wide fuel consumption, which may include stationary engines, non-road diesel vehicles and equipment (non-road diesels in surface and underground applications) and in explosives etc.

Over 99% of diesel consumed by EPA-licensed coal mines has a sulfur content of ≤ 10 ppm and complies with the *Fuel Standard (Automotive Diesel) Determination 2001* (Attorney-General's Department, 2009a), while less than 1% of diesel consumed (predominantly in underground applications) has a sulfur content of 50 – 500 ppm. At EPA-licensed coal mines, over 99% of diesel is consumed by non-road diesels in surface applications, while less than 1% is consumed in underground applications. Open-cut, combined open-cut and underground and underground coal mines consume 88%, 10% and 2%, respectively of all diesel consumed by EPA-licensed coal mines.

Table 7-8: Annual diesel consumption by coal mine type and surface equipment at EPA-licensed coal mines in 2012

Mine type	Surface/underground equipment	Diesel consumption (kL†/year) by sulfur content		Grand Total
		≤ 10 ppm sulfur	50 - 500 ppm sulfur	
Open-cut	Surface*	820,130		820,130
Open-cut & Underground	Surface*	93,370	2,083	95,453
Underground	Surface*	12,398	2,099	14,497
Surface Total*		**925,898**	**4,182**	**930,080**
Open-cut & Underground	Underground#	1,282		1,282
Underground	Underground#	1,331	3,746	5,078
Underground Total#		**2,613**	**3,746**	**6,360**
Grand Total		**928,511**	**7,928**	**936,440**
*Non-road diesels in surface applications #Non-road diesels in underground applications †kL = kilolitres (1,000 Litres)				

Annual diesel consumption by local government area (LGA) for the 58 coal mines that completed the survey is presented in Table 7-9 (EPA, 2013b). Approximately 80% of all diesel consumed by EPA-licensed coal mines is in Singleton and Muswellbrook LGAs, while nearly 95% of diesel is consumed in 6 LGA (Singleton, Muswellbrook, Mid-Western Regional, Narrabri, Great Lakes & Lithgow).

Table 7-9: Annual diesel consumption by LGA at EPA-licensed coal mines in 2012

LGA	Diesel consumption (kL†/year)	Proportion (%)	Cumulative proportion (%)
SINGLETON	478,380	51.1	51.1
MUSWELLBROOK	271,128	29.0	80.0
MID-WESTERN REGIONAL	55,053	5.9	85.9
NARRABRI	54,502	5.8	91.7
GREAT LAKES	13,735	1.5	93.2
LITHGOW	13,131	1.4	94.6
LIVERPOOL PLAINS	12,267	1.3	95.9
GUNNEDAH	11,809	1.3	97.2
CESSNOCK	9,279	1.0	98.2
GLOUCESTER	6,205	0.7	98.8
WOLLONDILLY	4,819	0.5	99.3
WOLLONGONG	3,349	0.4	99.7
LAKE MACQUARIE	2,294	0.2	99.9
WYONG	467	0.05	100.0
WINGECARRIBEE	21	0.002	100.0
Grand Total	**936,440**	**100.0**	
†kL = kilolitres (1,000 Litres)			

Annual diesel consumption by equipment description and emission standards certification for the 58 coal mines that completed the survey is presented in Table 7-10 (EPA, 2013b). This data is based on estimated non-road diesels individual equipment fuel consumption in surface applications using a model developed for this project (see Section 8.1.1 for further details). The annual diesel consumed by non-road diesels has been estimated at 919,327 kL/year or 99% of coal mine premises-wide fuel consumption in surface applications, which is reported to be 930,080 kL/year (EPA, 2013b). A linear regression of the estimated equipment vs. reported total premises-wide diesel consumption for surface equipment at EPA-licensed coal mines is shown in Figure 7-9. The linear regression exhibits a robust relationship with a coefficient of determination R^2 of 0.96. Although one coal mine data point is an outlier (estimated 154,855 kL/year), it is consistent with the coal mine's reported total diesel consumption in individual equipment (EPA, 2013b).

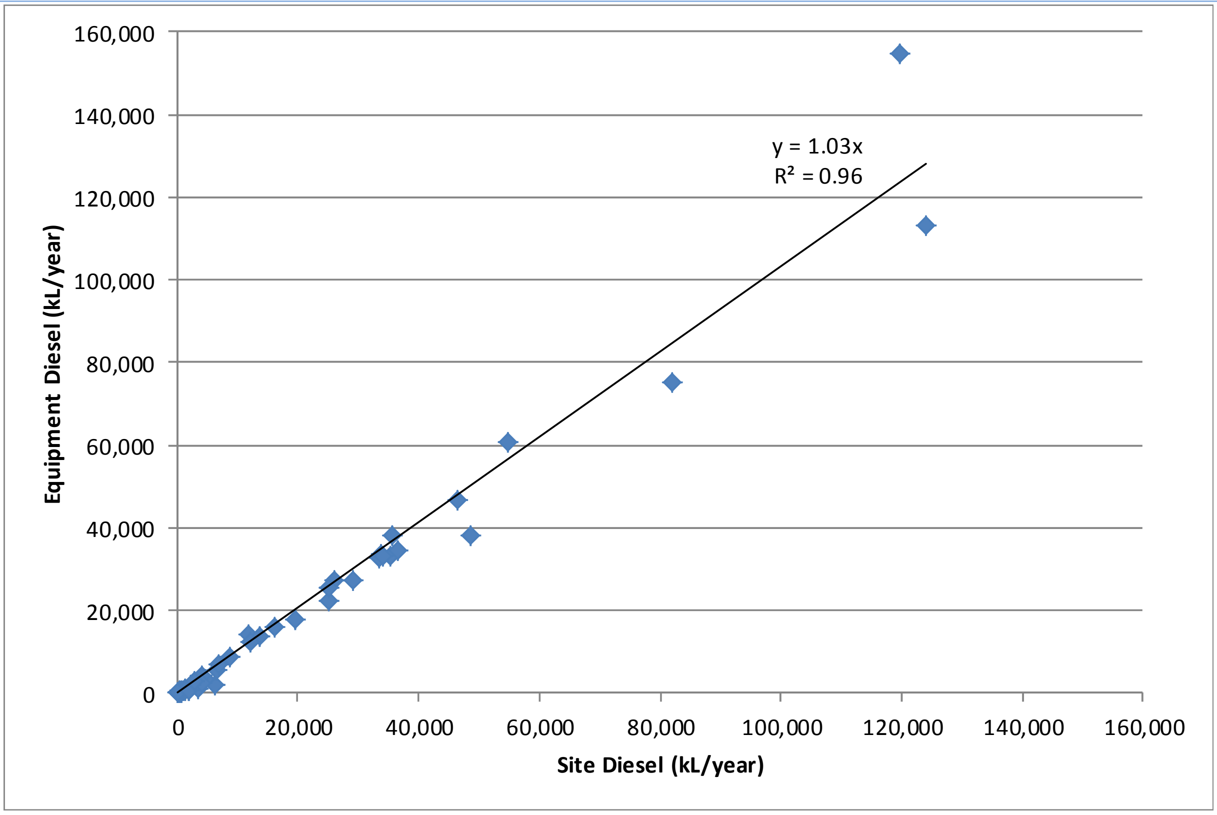


Figure 7-9: Estimated equipment vs. reported premises-wide diesel consumption for surface equipment at EPA-licensed coal mines in 2012

Approximately 81% of all diesel consumed by EPA-licensed coal mines is in off-highway trucks and excavators, while nearly 97% of diesel is consumed in four equipment types (off-highway trucks, excavators, crawler tractor/dozers and rubber tire loaders).

Approximately 31%, 45%, 21%, 2% and <1% of all diesel consumed by EPA-licensed coal mines is in US Tier 0, US Tier 1, US Tier 2/EU Stage II, US Tier 3/EU Stage III and US Tier 4 non-road diesels, respectively.

Table 7-10: Annual diesel consumption by equipment description and emission standards certification at EPA-licensed coal mines in 2012

Equipment description	Diesel consumption (kL†/year) by emission standards certification								Grand Total	Proportion (%)	Cumulative Proportion (%)
	US Tier 0	US Tier 1	EU Stage II	US Tier 2	EU Stage IIIA	US Tier 3	EU Stage IIIB	US Tier 4 interim			
Dsl - Off-highway Trucks	149,983	350,854		68,367		557		198	569,959	62.0%	62.0%
Dsl – Excavators	66,800	38,288		71,152		1,379			177,619	19.3%	81.3%
Dsl - Crawler Tractor/Dozers	42,097	11,645	356	42,385		13,471			109,955	12.0%	93.3%
Dsl - Rubber Tire Loaders	12,223	8,807	181	7,564		959			29,733	3.2%	96.5%
Dsl - Bore/Drill Rigs	6,706	4,867		5,138		1,681			18,392	2.0%	98.5%
Dsl – Graders	3,678	554		1,891		3,401		348	9,872	1.1%	99.6%
Dsl – Scrapers	2,047	0.3							2,047	0.2%	99.8%
Dsl – Pumps	1,021								1,021	0.1%	99.9%
Dsl – Forklifts	412	5	19	83	2		28	4	553	0.1%	100.0%
Dsl - Signal Boards/Light Plants								104	104	0.01%	100.0%
Dsl - Skid Steer Loaders	15	2		4		5		1	28	0.003%	100.0%
Dsl – Rollers	10	1		12					23	0.002%	100.0%
Dsl – Cranes	3					7			10	0.001%	100.0%
Dsl - Tractors/Loaders/Backhoes	5								5	0.001%	100.0%
Dsl – Welders	3								3	0.0004%	100.0%
Dsl - Air Compressors								2	2	0.0002%	100.0%
Dsl - Sweepers/Scrubbers	1								1	0.0001%	100.0%
Dsl - Aerial Lifts								0.2	0.2	0.00003%	100.0%
Grand Total	**285,004**	**415,023**	**556**	**196,597**	**2**	**21,459**	**28**	**658**	**919,327**	**100.0%**	
Proportion (%)	**31.0%**	**45.1%**	**0.1%**	**21.4%**	**0.0002%**	**2.3%**	**0.003%**	**0.1%**	**100.0%**		

†kL = kilolitres (1,000 Litres)

Annual diesel consumption by equipment ownership and emission standards certification for the 58 coal mines that completed the survey is presented in Table 7-11 and shown in Figure 7-10 (EPA, 2013b). Equipment owned by contractors and mine operators have been estimated to consume about 17% and 83% of diesel, respectively. For contractors, about 65% of diesel is consumed in US Tier 0 equipment[*]. In contrast for mine operators, about 24% of diesel is consumed in US Tier 0 equipment. While about 35% of diesel is consumed in at least US Tier 1 equipment for contractors, 76% of diesel is consumed in at least US Tier 1 equipment for mine operators.

Table 7-11: Annual diesel consumption by ownership and emission standards certification at EPA-licensed coal mines in 2012

Equipment ownership	Diesel consumption (kL†/year) by emission standards certification								Grand Total	Proportion (%)
	US Tier 0	US Tier 1	EU Stage II	US Tier 2	EU Stage IIIA	US Tier 3	EU Stage IIIB	US Tier 4 interim		
Contractor	105,646	24,649	302	23,041		6,049		457	160,145	17.4%
Mine Operator	179,357	390,374	254	173,556	2	15,410	28	201	759,182	82.6%
Grand Total	**285,004**	**415,023**	**556**	**196,597**	**2**	**21,459**	**28**	**658**	**919,327**	**100.0%**
Proportion (%)	**31.0%**	**45.1%**	**0.1%**	**21.4%**	**0.0002%**	**2.3%**	**0.003%**	**0.1%**	**100.0%**	
†kL = kilolitres (1,000 Litres)										

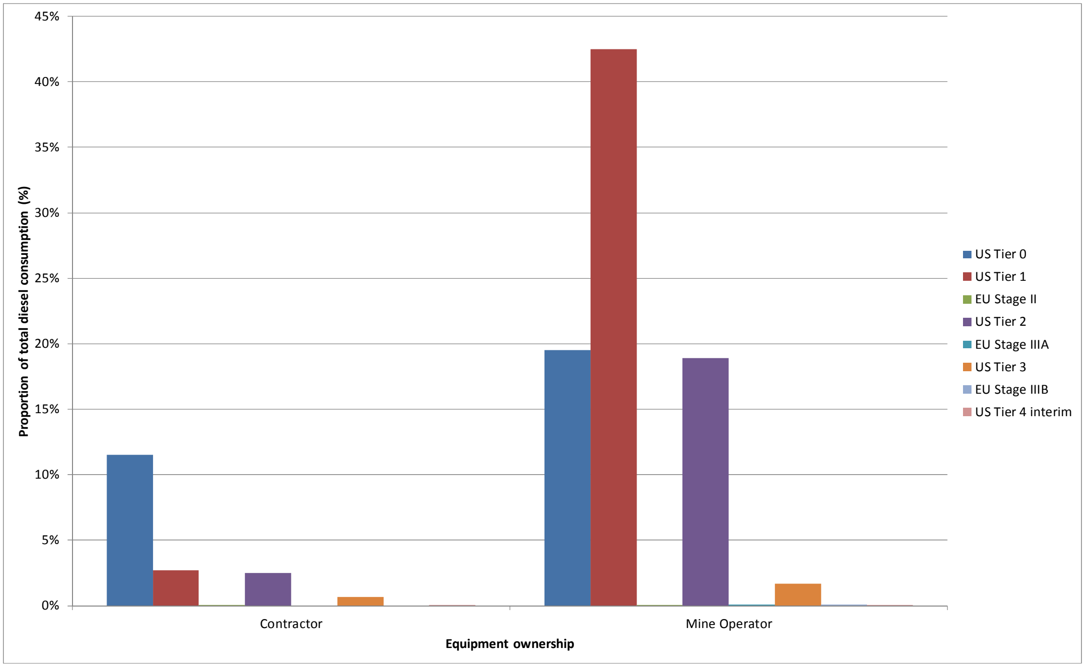


Figure 7-10: Annual diesel consumption by ownership and emission standards certification at EPA-licensed coal mines in 2012

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[*] 30% of contractor owned equipment has no reported year of manufacture (YOM), so it has been assumed to be US Tier 0. In contrast, 14% of mine operator owned equipment has no reported YOM. In terms of fuel consumption, the contractor owned equipment with no YOM are reported to consume 47% of the total contractor owned fleet diesel, while for mine owned equipment this is only 10%.

Annual diesel consumption by equipment description and horsepower (Hp) range for the 58 coal mines that completed the survey is presented in Table 7-12 (EPA, 2013b). Approximately 90% of all diesel consumed by EPA-licensed coal mines is in high power (≥ 750 Hp or 560 kW) equipment.

Table 7-12: Annual diesel consumption by equipment description and horsepower (Hp) range at EPA-licensed coal mines in 2012

Equipment description	Diesel consumption (kL†/year) by horsepower range (Hp)											
	25 to 50	50 to 75	75 to 100	100 to 175	175 to 300	300 to 600	600 to 750	750 to 1000	1000 to 1200	1200 to 2000	2000 to 3000	Grand Total
Dsl - Aerial Lifts	0.23											0.23
Dsl - Air Compressors	1.99											1.99
Dsl - Bore/Drill Rigs				61	41	4,490	2,976	8,401	189	2,233		18,392
Dsl - Cranes					9.55							9.55
Dsl - Crawler Tractor/Dozers					233	25,041	15,419	69,262				109,955
Dsl - Excavators	3.30	11	3.76	136	666	2,644	2,445	6,515	6,695	140,062	18,438	177,619
Dsl - Forklifts	17	83	49	404								553
Dsl - Graders				74	4,490	5,009	299					9,872
Dsl - Off-highway Trucks				39	442	3,916	8,087	12,366	4,616	145,285	395,208	569,959
Dsl - Pumps				289		732						1,021
Dsl - Rollers				15	8.21							23
Dsl - Rubber Tire Loaders	1.28	27	12	212	1,105	3,531	3,965	4,880	1,242	13,857	901	29,733
Dsl - Scrapers					0.31	2,047						2,047
Dsl - Signal Boards/Light Plants	104											104
Dsl - Skid Steer Loaders	6.64	19	2.09									28
Dsl - Sweepers/Scrubbers				1.08								1.08
Dsl - Tractors/Loaders/Backhoes			5.01									5.01
Dsl - Welders		3.49										3.49
Grand Total	**135**	**144**	**72**	**1,230**	**6,996**	**47,411**	**33,191**	**101,425**	**12,741**	**301,437**	**414,547**	**919,327**
Proportion (%)	**0.01%**	**0.02%**	**0.01%**	**0.13%**	**0.76%**	**5.16%**	**3.61%**	**11.03%**	**1.39%**	**32.79%**	**45.09%**	**100.00%**

7.2.3 Coal mine production

The saleable coal production for the 58 coal mines that completed the survey is presented in Table 7-13 and shown in Figure 7-11. The production data from 2012 to 2030 for existing EPA-licensed coal mines uses survey data for run-of-mine (ROM) coal (EPA, 2013b), which has been converted to saleable coal (Coal Services, 2003). The production data from 2012 to 2030 for proposed coal mines uses saleable coal forecasts (DRE, 2013). The cost benefit analysis (CBA) forecasts emission reductions and net monetary benefits over the period from 2012 to 2030 for existing EPA-licensed coal mines only. The data for proposed coal mine production has been included merely to illustrate the additional emission reductions and net monetary benefits that could potentially accrue by implementing measures to reduce emissions from non-road diesels.

At EPA-licensed coal mines, saleable coal production in 2012 has been estimated to be 176.9 Mt/year, increasing to 218.2 Mt/year in 2015 and then steadily declining to 167.2 Mt/year by 2030. When considering existing EPA-licensed and proposed coal mines together, saleable coal production in 2012 has been estimated to be 181.2 Mt/year, increasing to 316.6 Mt/year in 2021 and then steadily declining to 283.9 Mt/year in 2030.

Table 7-13: Saleable coal production by mine type at existing EPA-licensed coal mines and proposed coal mines from 2012 to 2030

Year	Saleable coal production (Mega tonne (Mt)/year) by mine type		Grand Total
	Existing*	Proposed#	
2012	176.9	4.3	181.2
2013	198.4	11.4	209.8
2014	206.5	15.5	222.0
2015	218.2	23.0	241.2
2016	212.3	31.9	244.2
2017	217.3	43.8	261.1
2018	211.9	65.7	277.5
2019	213.5	80.3	293.8
2020	213.5	96.2	309.7
2021	211.9	104.7	316.6
2022	207.4	103.2	310.6
2023	203.8	110.7	314.5
2024	197.6	112.7	310.3
2025	184.8	116.7	301.5
2026	180.3	116.7	297.0
2027	169.8	116.7	286.5
2028	174.5	116.7	291.2
2029	165.9	116.7	282.6
2030	167.2	116.7	283.9

* Survey data for run-of-mine (ROM) coal (EPA, 2013b) converted to saleable coal (Coal Services, 2003)
#Saleable coal forecasts (DRE, 2013)

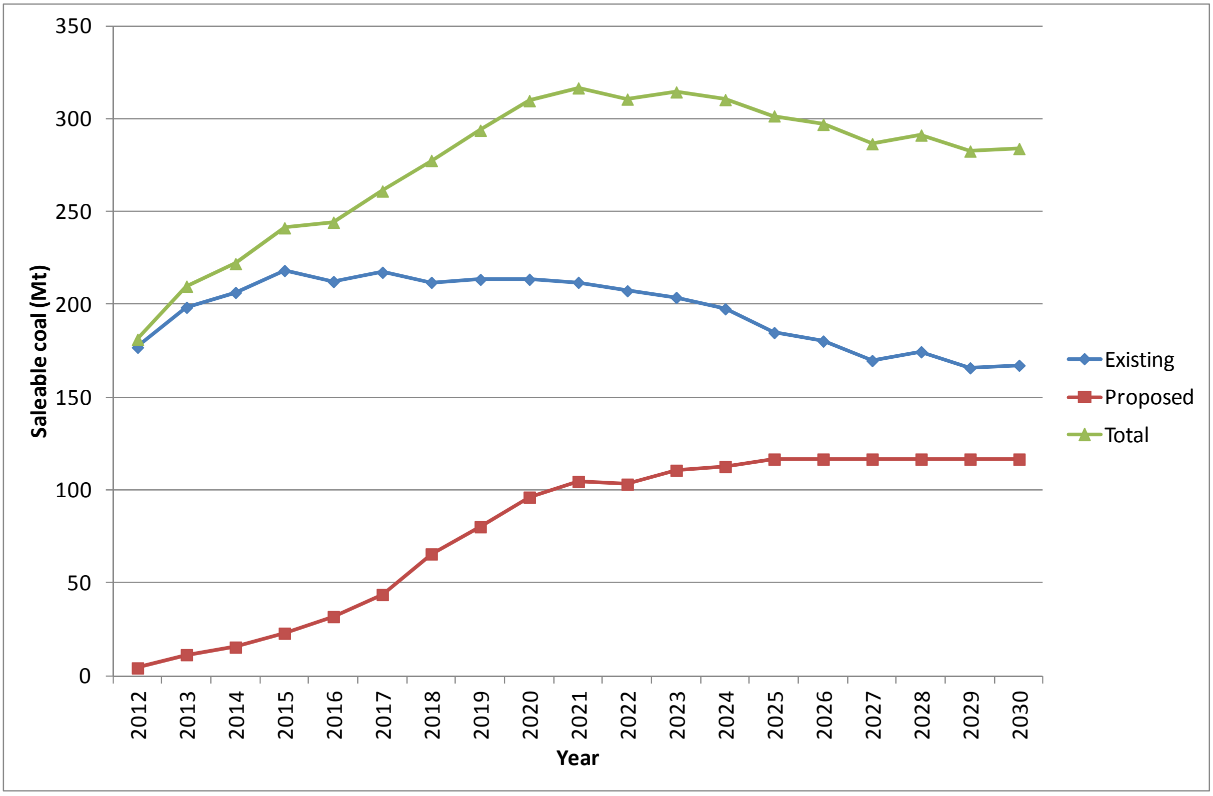

Figure 7-11: Saleable coal production by mine type at existing EPA-licensed coal mines and proposed coal mines from 2012 to 2030

The Mineral Council of Australia's Vision 2020 Project presents Australian Rail Track Corporation (ARTC) forecast saleable coal transport along various rail sections, based on consultation with the coal mining industry and these are listed in Table 7-14 (ACIL, 2009).

Table 7-14: ARTC forecast saleable coal transport by rail section

Rail Section	Forecast saleable coal transport (Mega tonne (Mt)/year)			
	2009	2014	2019	2024
Upper Hunter	93	128	115	117
Ulan line	29	64	75	102
Gunnedah basin	11	28	54	59
Total export	133	220	244	278

The 2014-2023 Hunter Valley Corridor Capacity Strategy presents ARTC forecast contracted and prospective saleable coal transport and these are listed in Table 7-15 (ARTC, 2014). The majority of export coal shipped from Newcastle port is transported to either the Carrington (Port Waratah) or Kooragang Island terminals by rail. Most of this coal originates from mines and coal loaders in the Hunter Valley and is transported by rail to the terminals using the railway line between Muswellbrook and Newcastle. Coal on this railway line also originates from mines and coal loaders in Ulan, the Gunnedah basin, Stratford, Pelton and the southern suburbs of Newcastle.

Table 7-15: ARTC forecast saleable coal transport by contracted or prospective

Contracted or Prospective	Forecast saleable coal transport (Mega tonne (Mt)/year)		
	2014	2019	2023
Contracted	184.1	191.5	191.5
Prospective	0	51.6	85.2
Total export	184.1	243.1	276.7

Forecast saleable coal transport in 2023 and 2024 have been estimated to be 276.7 (ARTC, 2014) and 278 Mt/year (ACIL, 2009) respectively, which are about 1.6 times saleable coal production at EPA-licensed coal mines in 2012 (176.9 Mt/year) (EPA, 2013b). When considering existing EPA-licensed and proposed coal mines together, saleable coal production in 2024 has been estimated to be 310.3 Mt/year (EPA, 2013b & DRE, 2013), which is about 1.75 times saleable coal production at EPA-licensed coal mines in 2012 (176.9 Mt/year) (EPA, 2013b).

The 2012 run-of-mine (ROM) coal production reported in the survey for each of the 64 coal mines in NSW that hold a current environment protection licence (EPL) (EPA, 2013a) is presented in Table 7-16 (EPA, 2013b), including the EPL number, premises name, suburb, local government area (LGA), mine type, operational status, reporting year, whether surface equipment are used and if they were exempt from survey.

At EPA-licensed coal mines, ROM coal production in 2012 has been estimated to be 225.2 Mt/year, with open-cut, underground and combined open-cut and underground coal mines producing 148, 46.8 and 30.4 Mt/year, respectively.

Table 7-16: Run-of-mine coal production at EPA-licensed coal mines in 2012

EPL	Premises	Suburb	LGA	Mine type*	Status	ROM coal production (Mega tonne (Mt)/year)	Reporting year	Surface equipment	Exempt
191	MANNERING COLLIERY	DOYALSON	WYONG	UG	Temporarily Closed - Care & Maintenance	0.4	2012 Calendar Year	No	No
365	MANDALONG MINE, COORANBONG COLLIERY AND DELTA COAL SERVICES SITE	DORA CREEK	LAKE MACQUARIE	UG	Operational	5.4	2012 Calendar Year	Yes	No
366	MYUNA COLLIERY	WANGI WANGI	LAKE MACQUARIE	UG	Operational	1.4	2012 Calendar Year	Yes	No
394	ULAN COAL MINES LIMITED	MUDGEE	MID-WESTERN REGIONAL	OC & UG	Operational	7.1	2012 Calendar Year	Yes	No
395	NEWSTAN COLLIERY	FASSIFERN	LAKE MACQUARIE	UG	Operational	0.5	2012 Calendar Year	Yes	No
396	BLOOMFIELD COLLIERY	ASHTONFIELD	CESSNOCK	OC	Operational	0.8	2011/12 Fiscal Year for Fuel Usage/ 2012 Calendar Year for Equipment Data	Yes	No
416	AUSTAR COAL MINE	PELTON	CESSNOCK	UG	Operational	1.7	2012 Calendar Year	Yes	No
443	AWABA COLLIERY	AWABA	LAKE MACQUARIE	UG	Permanently Closed - Rehabilitation Operations Only	0.0	April 2012 - April 2013	Yes	No
467	ANGUS PLACE COLLIERY	LIDSDALE	LITHGOW	UG	Operational	3.7	2012 Calendar Year	Yes	No

EPL	Premises	Suburb	LGA	Mine type*	Status	ROM coal production (Mega tonne (Mt)/year)	Reporting year	Surface equipment	Exempt
528	CHARBON COAL PTY LIMITED	CHARBON	MID-WESTERN REGIONAL	OC & UG	Operational	1.3	2012 Calendar Year	Yes	No
529	WAMBO COAL PTY LTD	WARKWORTH	SINGLETON	OC & UG	Operational	9.4	2012 Calendar Year	Yes	No
563	SAXONVALE COLLIERY HOLDING	SINGLETON	SINGLETON	OC	Operational	10.0	2012 Calendar Year	Yes	No
608	BERRIMA COLLIERY	MEDWAY	WINGECARRIBEE	UG	Operational	0.2	2012 Calendar Year	Yes	No
611	CORDEAUX COLLIERY	WOLLONGONG	WOLLONGONG	UG	Temporarily Closed - Care & Maintenance	0.0	2012 Calendar Year	No	Yes
631	IVANHOE NO.2 COLLIERY	PORTLAND	LITHGOW	OC	Permanently Closed - Rehabilitation Operations Only	0.0	2012 Calendar Year	No	Yes
640	HUNTER VALLEY OPERATIONS	SINGLETON	SINGLETON	OC	Operational	16.0	2012 Calendar Year	Yes	No
656	MUSWELLBROOK COLLIERY HOLDING	MUSWELLBROOK	MUSWELLBROOK	OC	Operational	1.1	2011/12 Fiscal year	Yes	No
726	CLARENCE COLLIERY	NEWNES JUNCTION	LITHGOW	UG	Operational	2.0	2012 Calendar Year	Yes	No
765	BAAL BONE COLLIERY	LITHGOW	LITHGOW	UG	Temporarily Closed - Care & Maintenance	0.0	2012 Calendar Year	No	No
767	METROPOLITAN COLLIERY	HELENSBURGH	WOLLONGONG	UG	Operational	2.0	2012 Calendar Year	Yes	No
1087	NRE WONGAWILLI COLLIERY	WONGAWILLI	WOLLONGONG	UG	Operational	0.8	2012 Calendar Year	Yes	No

EPL	Premises	Suburb	LGA	Mine type*	Status	ROM coal production (Mega tonne (Mt)/year)	Reporting year	Surface equipment	Exempt
1095	THE INVINCIBLE COLLIERY	CULLEN BULLEN	LITHGOW	OC	Temporarily Closed - Care & Maintenance	0.9	2012 Calendar Year	Yes	No
1323	DRAYTON COAL MINE	MUSWELLBROOK	MUSWELLBROOK	OC	Operational	5.5	2012 Calendar Year	Yes	No
1360	OCEANIC COAL AUSTRALIA LIMITED	TERALBA	LAKE MACQUARIE	UG	Operational	4.3	2012 Calendar Year	No	No
1376	WARKWORTH COAL MINE	MOUNT THORLEY	SINGLETON	OC	Operational	11.7	2012 Calendar Year	Yes	No
1389	TAHMOOR COLLIERY	TAHMOOR	WOLLONDILLY	UG	Operational	2.5	2012 Calendar Year	Yes	No
1770	CHAIN VALLEY COLLIERY	CHAIN VALLEY BAY	WYONG	UG	Operational	0.8	May 2012 - April 2013	Yes	No
1976	MOUNT THORLEY OPERATIONS	MOUNT THORLEY	SINGLETON	OC	Operational	5.1	2012 Calendar Year	Yes	No
2094	LIDDELL COAL OPERATIONS	RAVENSWORTH	MUSWELLBROOK	OC	Operational	6.9	2012 Calendar Year	Yes	No
2504	WEST CLIFF AND NORTH CLIFF COLLIERIES	APPIN	WOLLONDILLY	UG	Operational	5.9	2012 Calendar Year	Yes	No
2652	RAVENSWORTH MINING COMPLEX	RAVENSWORTH	SINGLETON	OC & UG	Operational	8.0	2012 Calendar Year	Yes	No
3141	UNITED COLLIERY	WARKWORTH	SINGLETON	UG	Temporarily Closed - Care & Maintenance	0.0	2012 Calendar Year	Yes	No
3241	DENDROBIUM MINE	MOUNT KEMBLA	WOLLONGONG	UG	Operational	4.2	2012 Calendar Year	Yes	No
3390	INTEGRA COAL COMPLEX	SINGLETON	SINGLETON	OC & UG	Operational	4.6	2012 Calendar Year	Yes	No

EPL	Premises	Suburb	LGA	Mine type*	Status	ROM coal production (Mega tonne (Mt)/year)	Reporting year	Surface equipment	Exempt
3391	RIX'S CREEK COLLIERY	SINGLETON	SINGLETON	OC	Operational	2.7	2011/12 Fiscal Year for Fuel Usage/ 2012 Calendar Year for Equipment Data	Yes	No
3607	SPRINGVALE COLLIERY	LIDSDALE	LITHGOW	UG	Operational	2.4	2012 Calendar Year	Yes	No
4460	MT OWEN COAL MINE	RAVENSWORTH	SINGLETON	OC	Operational	8.1	2012 Calendar Year	Yes	No
4885	DARTBROOK COAL MINE	MUSWELLBROOK	MUSWELLBROOK	UG	Temporarily Closed - Care & Maintenance	0.0	2012 Calendar Year	No	No
4911	PINE DALE MINE	LIDSDALE	LITHGOW	OC	Operational	0.2	2012 Calendar Year	Yes	No
5161	STRATFORD COAL MINE	STRATFORD	GLOUCESTER	OC	Operational	0.7	2011/12 Fiscal year	Yes	No
6538	BENGALLA MINE	MUSWELLBROOK	MUSWELLBROOK	OC	Operational	8.4	2012 Calendar Year	Yes	No
10094	CANYON COAL MINE	BOGGABRI	NARRABRI	OC	Permanently Closed - Rehabilitation Operations Only	0.0	2012 Calendar Year	No	Yes
10341	CULLEN VALLEY MINE	CULLEN BULLEN	LITHGOW	OC	Temporarily Closed - Care & Maintenance	0.5	2012 Calendar Year	Yes	No
10860#	RAVENSWORTH EAST MINE	RAVENSWORTH	SINGLETON	OC	Operational	4.0	2012 Calendar Year	Yes	No
11080	DONALDSON COAL	MAITLAND	MAITLAND	OC	Permanently	0.0	2013/14	No	Yes

EPL	Premises	Suburb	LGA	Mine type*	Status	ROM coal production (Mega tonne (Mt)/year)	Reporting year	Surface equipment	Exempt
	PTY LTD				Closed - Rehabilitation Operations Only		Fiscal year		
11457	MT ARTHUR COAL	MUSWELLBROOK	MUSWELLBROOK	OC	Operational	21.5	2011/12 Fiscal year	Yes	No
11701	DURALIE COAL MINE	STROUD ROAD	GREAT LAKES	OC	Operational	2.5	2011/12 Fiscal year	Yes	No
11745	BOWENS ROAD NORTH COAL PROJECT	STRATFORD	GLOUCESTER	OC	Operational	0.3	2011/12 Fiscal year	Yes	No
11879	ASHTON COAL MINE	CAMBERWELL	SINGLETON	UG	Operational	2.3	2012 Calendar Year	Yes	No
12040	NRE NO 1 COLLIERY	RUSSELL VALE	WOLLONGONG	UG	Operational	0.5	2012 Calendar Year	Yes	No
12290	WERRIS CREEK COAL	WERRIS CREEK	LIVERPOOL PLAINS	OC	Operational	1.3	2011/12 Fiscal year	Yes	No
12365	TARRAWONGA COAL MINE	BOGGABRI	NARRABRI	OC	Operational	2.0	2011/12 Fiscal year	Yes	No
12374	AIRLY MINE	CAPERTEE	LITHGOW	UG	Temporarily Closed - Care & Maintenance	0.9	2012 Calendar Year	Yes	No
12407	BOGGABRI COAL MINE	BOGGABRI	NARRABRI	OC	Operational	3.7	2012 Calendar Year	Yes	No
12425	WILPINJONG COAL PTY LTD	MUDGEE	MID-WESTERN REGIONAL	OC	Operational	14.7	2012 Calendar Year	Yes	No
12483	TASMAN COAL MINE	SEAHAMPTON	LAKE MACQUARIE	UG	Permanently Closed - Rehabilitation Operations Only	0.0	2013/14 Fiscal year	No	Yes
12789	NARRABRI COAL OPERATIONS	BAAN BAA	NARRABRI	UG	Operational	3.0	April 2012 - March 2013	Yes	No

EPL	Premises	Suburb	LGA	Mine type*	Status	ROM coal production (Mega tonne (Mt)/year)	Reporting year	Surface equipment	Exempt
12840#	GLENDELL MINE	RAVENSWORTH	SINGLETON	OC	Operational	4.0	2012 Calendar Year	Yes	No
12856	ABEL UNDERGROUND MINE	BLACK HILL	CESSNOCK	UG	Operational	1.9	April 2012 - March 2013	No	No
12870	ROCGLEN COAL MINE	GUNNEDAH	GUNNEDAH	OC	Operational	1.4	2011/12 Fiscal year	Yes	No
12894	XSTRATA MANGOOLA	WYBONG	MUSWELLBROOK	OC	Operational	10.5	2012 Calendar Year	Yes	No
12932	MOOLARBEN COAL MINE	MUDGEE	MID-WESTERN REGIONAL	OC	Operational	7.2	2012 Calendar Year	Yes	No
12957	SUNNYSIDE COAL PROJECT	GUNNEDAH	GUNNEDAH	OC	Temporarily Closed - Care & Maintenance	0.5	2011/12 Fiscal year	Yes	No
13063	IVANHOE NORTH REHABILITATION PROJECT	CULLEN BULLEN	LITHGOW	OC	Permanently Closed - Rehabilitation Operations Only	0.0	2012 Calendar Year	No	Yes

*OC – open-cut, UG – underground, OC & UG – combined open-cut and underground
#Combined production of EPL 10860 and 12840 are 4.0 Mega tonne (Mt)/year

7.2.4 Equipment fleet specification and activity

The number and average age of equipment as a function of US Tier 0 to Tier 4 emissions standards certification for the 58 coal mines that completed the survey is presented in Table 7-17 and shown in Figure 7-12 (EPA, 2013b)[†]. Out of 2,436 non-road diesels, about 91.5% (42% Tier 0, 28% Tier 1 & 21.5% Tier 2/EU Stage II) are US Tier 2/EU Stage II or lower, while the remaining 8.5% (7.5% Tier 3/EU Stage IIIA & 1% Tier 4i/EU Stage IIIB) are US Tier 3/EU Stage IIIA or higher. The average age of all non-road diesels is ten years, while the average age obviously decreases from older US Tier 0 (16.6 years) to newer US Tier 4i (2.5 years) technologies.

Table 7-17: Equipment number and average age by emission standards certification at EPA-licensed coal mines in 2012

Emission standards certification	Equipment number	Average age (years)
US Tier 0	1,027	16.6
US Tier 1	675	6.3
EU Stage II	6	8.2
US Tier 2	522	4.1
EU Stage IIIA	2	3.0
US Tier 3	185	3.8
EU Stage IIIB	1	1.0
US Tier 4 interim	18	2.5
Grand Total	**2,436**	**10.0**

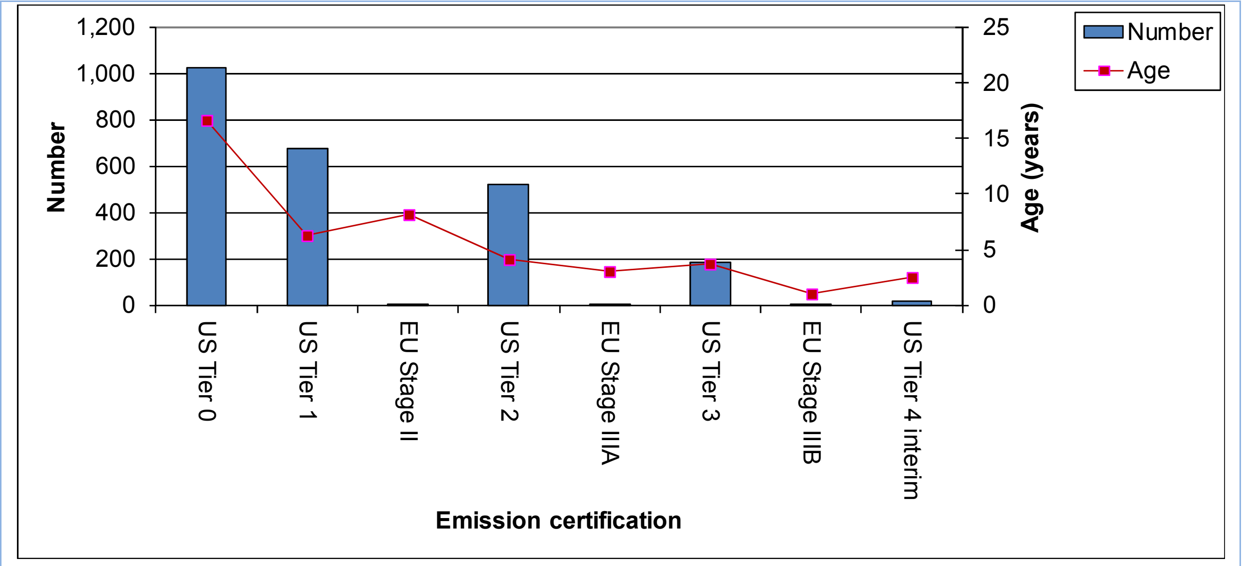

Figure 7-12: Equipment number and average age by emission standards certification at EPA-licensed coal mines in 2012

The number and average age of equipment as a function of equipment description and US Tier 0 to Tier 4 emissions standards certification for the 58 coal mines that completed the survey is presented in Table 7-19.

[†] Equipment with no reported year of manufacture (YOM) has been assumed to be US Tier 0.

Approximately 68% of all non-road diesels at EPA-licensed coal mines are off-highway trucks and crawler tractor/dozers, while over 86% of non-road diesels include four equipment types (off-highway trucks, crawler tractor/dozers, excavators and rubber tire loaders).

The number and average age of equipment as a function of ownership and US Tier 0 to Tier 4 emissions standards certification for the 58 coal mines that completed the survey is presented in Table 7-18 and shown in Figure 7-13 (EPA, 2013b). Out of 2,436 non-road diesels, about 41.5% are owned by contractors, while the remaining 58.5% are owned by mine operators. For contractor owned equipment, about 51% are US Tier 0[‡]. In contrast for mine operator owned equipment, about 36% are US Tier 0. While about 49% of contractor owned equipment are at least US Tier 1, 64% of mine operator owned equipment are at least US Tier 1.

Table 7-18: Equipment number and average age by ownership and emission standards certification at EPA-licensed coal mines in 2012

Equipment ownership	Emission standards certification	Equipment number	Average age (years)
Contractor	US Tier 0	511	17.1
	US Tier 1	190	9.8
	EU Stage II	3	8.7
	US Tier 2	160	6.4
	US Tier 3	126	3.9
	US Tier 4 interim	16	2.6
Contractor Total		**1,006**	**12.1**
Mine Operator	US Tier 0	516	16.2
	US Tier 1	485	4.9
	EU Stage II	3	7.7
	US Tier 2	362	3.1
	EU Stage IIIA	2	3.0
	US Tier 3	59	3.5
	EU Stage IIIB	1	1.0
	US Tier 4 interim	2	2.0
Mine Operator Total		**1,430**	**8.4**
Grand Total		**2,436**	**10.0**

[‡] 30% of contractor owned equipment has no reported year of manufacture (YOM), so it has been assumed to be US Tier 0. In contrast, 14% of mine operator owned equipment has no reported YOM. In terms of fuel consumption, the contractor owned equipment with no YOM are reported to consume 47% of the total contractor owned fleet diesel, while for mine owned equipment this is only 10%.

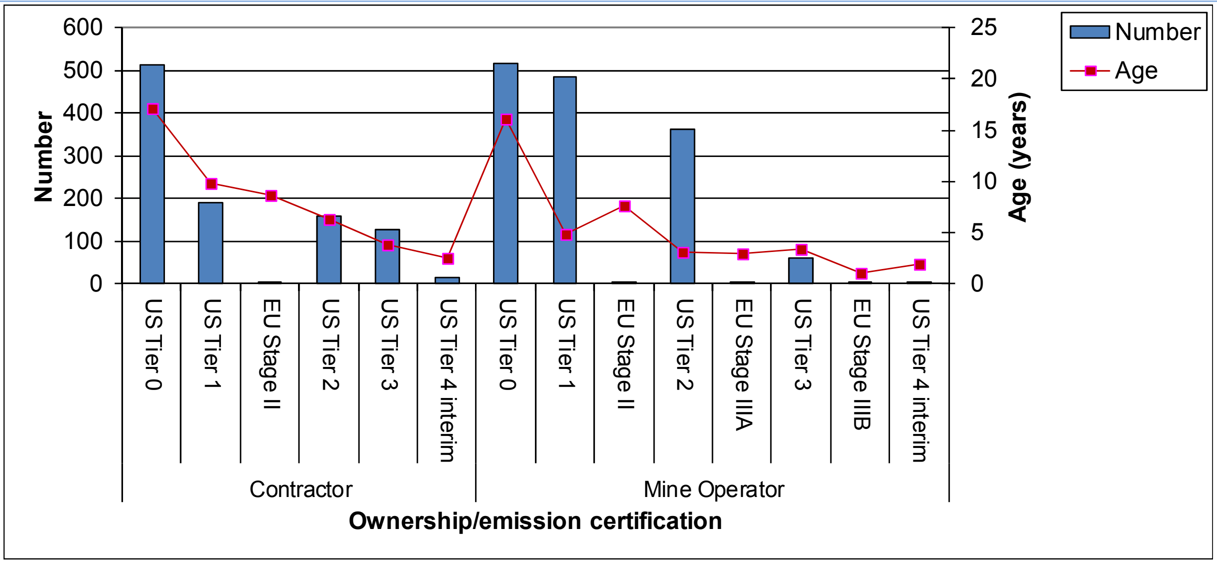

Figure 7-13: Equipment number and average age by ownership and emission standards certification at EPA-licensed coal mines in 2012.

Table 7-19: Equipment number by equipment description and emission standards certification at EPA-licensed coal mines in 2012

Equipment description	Equipment number by emission standards certification								Grand Total	Proportion (%)	Cumulative Proportion (%)
	US Tier 0	US Tier 1	EU Stage II	US Tier 2	EU Stage IIIA	US Tier 3	EU Stage IIIB	US Tier 4 interim			
Dsl - Off-highway Trucks	430	528		188		36		2	1,184	48.6%	48.6%
Dsl - Crawler Tractor/Dozers	190	45	2	178		51			466	19.1%	67.7%
Dsl – Excavators	97	44		68		50			259	10.6%	78.4%
Dsl - Rubber Tire Loaders	131	22	3	25		8			189	7.8%	86.1%
Dsl – Graders	48	5		25		28		1	107	4.4%	90.5%
Dsl - Bore/Drill Rigs	50	14		19	1	8			92	3.8%	94.3%
Dsl – Forklifts	28	1	1	8	1		1	3	43	1.8%	96.1%
Dsl – Scrapers	24	3							27	1.1%	97.2%
Dsl – Rollers	1	12		10					23	0.9%	98.1%
Dsl – Pumps	19								19	0.8%	98.9%
Dsl - Signal Boards/Light Plants								9	9	0.4%	99.3%
Dsl - Skid Steer Loaders	3	1		1		2		1	8	0.3%	99.6%
Dsl - Tractors/Loaders/Backhoes	3								3	0.1%	99.7%
Dsl – Cranes	1					2			3	0.1%	99.8%
Dsl - Sweepers/Scrubbers	1								1	0.04%	99.9%
Dsl – Welders	1								1	0.04%	99.9%
Dsl - Air Compressors								1	1	0.04%	100.0%
Dsl - Aerial Lifts								1	1	0.04%	100.0%
Grand Total	**1,027**	**675**	**6**	**522**	**2**	**185**	**1**	**18**	**2,436**	**100.0%**	
Proportion (%)	**42.2%**	**27.7%**	**0.2%**	**21.4%**	**0.1%**	**7.6%**	**0.04%**	**0.7%**	**100%**		

Table 7-20 to Table 7-27 summarise salient data by equipment description for the 58 coal mines that completed the survey, which has been used in the fuel consumption and emissions model (based on the *NONROAD2008a Model* (USEPA, 2009b)), including:

- Table 7-20 - engine population, total power & average power by equipment description
- Table 7-21 - annual average engine & equipment use
- Table 7-22 - average cumulative (since last engine rebuild) engine use
- Table 7-23 – average engine life
- Table 7-24 - average cumulative (since new) equipment use
- Table 7-25 – average equipment life
- Table 7-26 – average engine load factor
- Table 7-27 – annual diesel consumption.

Table 7-20: Equipment number, engine number, total horsepower and average horsepower by equipment description at EPA-licensed coal mines in 2012

Equipment description	Equipment number	Engine number	Total horsepower (hp)	Average horsepower (hp)
Dsl - Aerial Lifts	1	1	34	34
Dsl - Air Compressors	1	1	47	47
Dsl - Bore/Drill Rigs	92	94	64,010	681
Dsl – Cranes	3	3	825	275
Dsl - Crawler Tractor/Dozers	466	466	338,730	727
Dsl – Excavators	259	325	353,127	1,087
Dsl – Forklifts	43	43	4,584	107
Dsl – Graders	107	107	32,435	303
Dsl - Off-highway Trucks	1,184	1,262	2,406,054	1,907
Dsl – Pumps	19	19	5,794	305
Dsl – Rollers	23	23	3,387	147
Dsl - Rubber Tire Loaders	189	190	114,132	601
Dsl – Scrapers	27	48	22,366	466
Dsl - Signal Boards/Light Plants	9	9	253	28
Dsl - Skid Steer Loaders	8	8	478	60
Dsl - Sweepers/Scrubbers	1	1	139	139
Dsl - Tractors/Loaders/Backhoes	3	3	348	116
Dsl – Welders	1	1	58	58
Grand Total	**2,436**	**2,604**	**3,346,803**	**1,285**

Table 7-21: Annual average engine/equipment use by equipment description at EPA-licensed coal mines in 2012

Equipment description	Annual average engine/equipment use (hours/year)
Dsl - Aerial Lifts	54
Dsl - Air Compressors	309
Dsl - Bore/Drill Rigs	2,781
Dsl – Cranes	202
Dsl - Crawler Tractor/Dozers	3,444
Dsl – Excavators	4,445
Dsl – Forklifts	1,490
Dsl – Graders	2,750
Dsl - Off-highway Trucks	3,568
Dsl – Pumps	2,750
Dsl – Rollers	64
Dsl - Rubber Tire Loaders	2,080
Dsl – Scrapers	1,238
Dsl - Signal Boards/Light Plants	3,899
Dsl - Skid Steer Loaders	732
Dsl - Sweepers/Scrubbers	58
Dsl - Tractors/Loaders/Backhoes	336
Dsl – Welders	899
Grand Total	**3,333**

Table 7-22: Average cumulative engine use by equipment description at EPA-licensed coal mines in 2012

Equipment description	Average cumulative engine use (hours)
Dsl - Aerial Lifts	657
Dsl - Air Compressors	1,516
Dsl - Bore/Drill Rigs	9,313
Dsl – Cranes	7,951
Dsl - Crawler Tractor/Dozers	9,277
Dsl – Excavators	9,671
Dsl – Forklifts	6,069
Dsl – Graders	10,208
Dsl - Off-highway Trucks	11,396
Dsl – Pumps	24,592
Dsl – Rollers	4,665
Dsl - Rubber Tire Loaders	11,982
Dsl – Scrapers	12,840
Dsl - Signal Boards/Light Plants	8,446
Dsl - Skid Steer Loaders	3,525
Dsl - Sweepers/Scrubbers	17,973
Dsl - Tractors/Loaders/Backhoes	13,991
Dsl – Welders	938
Grand Total	**10,636**

Table 7-23: Average engine life by equipment description at EPA-licensed coal mines

Equipment description	Average engine life (hours)
Dsl - Aerial Lifts	18,076
Dsl - Air Compressors	18,076
Dsl - Bore/Drill Rigs	15,370
Dsl – Cranes	18,076
Dsl - Crawler Tractor/Dozers	15,579
Dsl – Excavators	16,752
Dsl – Forklifts	10,900
Dsl – Graders	15,698
Dsl - Off-highway Trucks	19,982
Dsl – Pumps	18,076
Dsl – Rollers	8,050
Dsl - Rubber Tire Loaders	18,818
Dsl – Scrapers	14,182
Dsl - Signal Boards/Light Plants	18,076
Dsl - Skid Steer Loaders	11,500
Dsl - Sweepers/Scrubbers	18,076
Dsl - Tractors/Loaders/Backhoes	14,025
Dsl – Welders	18,076
Grand Total	**17,918**

Table 7-24: Average cumulative equipment use by equipment description at EPA-licensed coal mines in 2012

Equipment description	Average cumulative equipment use (hours)
Dsl - Aerial Lifts	657
Dsl - Air Compressors	1,516
Dsl - Bore/Drill Rigs	21,031
Dsl - Cranes	2,940
Dsl - Crawler Tractor/Dozers	21,563
Dsl - Excavators	17,426
Dsl - Forklifts	4,131
Dsl - Graders	19,711
Dsl - Off-highway Trucks	23,790
Dsl - Pumps	24,591
Dsl - Rollers	4,665
Dsl - Rubber Tire Loaders	23,572
Dsl - Scrapers	7,625
Dsl - Signal Boards/Light Plants	8,446
Dsl - Skid Steer Loaders	1,163
Dsl - Sweepers/Scrubbers	21,612
Dsl - Tractors/Loaders/Backhoes	8,041
Dsl - Welders	938
Grand Total	**21,482**

Table 7-25: Average equipment life by equipment description at EPA-licensed coal mines

Equipment description	Average equipment life (hours)
Dsl - Aerial Lifts	20,000
Dsl - Air Compressors	20,000
Dsl - Bore/Drill Rigs	56,603
Dsl - Cranes	40,000
Dsl - Crawler Tractor/Dozers	57,484
Dsl - Excavators	54,758
Dsl - Forklifts	33,222
Dsl - Graders	58,134
Dsl - Off-highway Trucks	68,074
Dsl - Pumps	20,000
Dsl - Rollers	21,739
Dsl - Rubber Tire Loaders	63,778
Dsl - Scrapers	32,500
Dsl - Signal Boards/Light Plants	20,000
Dsl - Skid Steer Loaders	16,833
Dsl - Sweepers/Scrubbers	61,932
Dsl - Tractors/Loaders/Backhoes	36,667
Dsl - Welders	20,000
Grand Total	**61,127**

Table 7-26: Average engine load factor by equipment description at EPA-licensed coal mines

Equipment description	Average engine load factor (%)
Dsl - Aerial Lifts	49
Dsl - Air Compressors	62
Dsl - Bore/Drill Rigs	52
Dsl - Cranes	30
Dsl - Crawler Tractor/Dozers	48
Dsl - Excavators	45
Dsl - Forklifts	39
Dsl - Graders	46
Dsl - Off-highway Trucks	32
Dsl - Pumps	35
Dsl - Rollers	48
Dsl - Rubber Tire Loaders	49
Dsl - Scrapers	52
Dsl - Signal Boards/Light Plants	48
Dsl - Skid Steer Loaders	38
Dsl - Sweepers/Scrubbers	68
Dsl - Tractors/Loaders/Backhoes	21
Dsl - Welders	26
Grand Total	**40**

Table 7-27: Annual diesel consumption by equipment description at EPA-licensed coal mines in 2012

Equipment description	Annual diesel consumption (kL†/year)
Dsl - Aerial Lifts	0.2
Dsl - Air Compressors	2
Dsl - Bore/Drill Rigs	18,392
Dsl - Cranes	10
Dsl - Crawler Tractor/Dozers	109,955
Dsl - Excavators	177,619
Dsl - Forklifts	553
Dsl - Graders	9,872
Dsl - Off-highway Trucks	569,959
Dsl - Pumps	1,021
Dsl - Rollers	23
Dsl - Rubber Tire Loaders	29,733
Dsl - Scrapers	2,047
Dsl - Signal Boards/Light Plants	104
Dsl - Skid Steer Loaders	28
Dsl - Sweepers/Scrubbers	1
Dsl - Tractors/Loaders/Backhoes	5
Dsl - Welders	3
Grand Total	**919,327**
†kL = kilolitres (1,000 Litres)	

7.2.5 Equipment maintenance and engine replacement strategies

A series of questions about equipment maintenance and engine replacement strategies were asked in the survey of EPA-licensed coal mines (EPA, 2013b) and the results are summarised in this section.

- (1) Do you adhere to documented equipment specific engine maintenance schedules based on manufacturer's recommendations?

Yes	94%
No	6%

- (2) Who performs the engine systems maintenance?

Contractors	12%
Mine company staff	21%
Other	9%
All or any of above	58%

- (3) Are records kept to verify engine maintenance schedules are adhered to?

Yes	**100%**

- (4) Are engine maintenance records subject to periodic audit?

Yes	**73%**
No	**27%**

- (5) Does the engine maintenance system fall under part of an accredited quality system?

Yes	**15%**
No	**85%**

- (6) Do you have documented procedures (or other mechanisms) for identifying, recording, and rectifying:
  - (a) Excessive Fuel Consumption

Yes	**70%**
No	**30%**

  - (b) Excessive Oil Consumption

Yes	**73%**
No	**27%**

  - (c) Excessive Smoke Emissions

Yes	**55%**
No	**45%**

Responses to questions about equipment maintenance strategies indicate that emissions performance for non-road diesel engines at coal mines could potentially be improved through systematic auditing of maintenance records (73%), adopting an accredited quality system for engine maintenance (15%), including documented procedures for dealing with excessive fuel (70%) & oil (73%) consumption and smoke (55%) emissions.

- (7) Which engine replacement strategies were applied in the latest reporting year?
  - (a) Rebuild engine to original specification

Yes	**97%**
No	**3%**

  - (b) Rebuild engine to original and improve emissions performance with addition of exhaust aftertreatment

Yes	**6%**
No	**94%**

  - (c) Repower with current engine model to latest emissions certification practically available

Yes	**15%**
No	**85%**

Responses to questions about engine replacement strategies indicate that non-road diesel engines at coal mines are largely rebuilt (97%) to original specification although a significant proportion are repowered (15%) with the latest practical technology available. A very small proportion of engines are fitted with exhaust aftertreatment (6%).

8 ESTIMATED COSTS AND BENEFITS OF REDUCING NON-ROAD DIESEL ENGINE PARTICULATE MATTER AT NSW COAL MINES

This section describes the diesel non-road vehicles and equipment (non-road diesels) fuel consumption and emissions estimation model developed for this project. The cost benefit analysis (CBA) methodology is also described, including unit damage costs for particulate matter (PM), along with equipment capital, maintenance and operating costs for new replacement non-road diesels and retrofit exhaust aftertreatment equipment for in-service non-road diesels. A number of retrofit, replacement and combined retrofit and replacement options for reducing non-road diesel exhaust emissions are presented in detail and a summary of the CBA is included. Unquantified benefits are discussed and a sensitivity analysis for key assumptions is presented.

8.1 Fuel Consumption and Emissions Model and Cost Benefit Analysis Methodology

This section describes the non-road diesels fuel consumption and emissions estimation model developed for this project and the CBA methodology.

The main focus of this project is about non-road diesels used at open-cut rather than underground coal mines (except for surface equipment). Since non-road diesels at underground coal mines are regulated by the Division of Resources and Energy (DRE) under the *Coal Mine Health and Safety Act 2002* (CMHS Act) (PCO, 2013b) (refer to Section 4.3 for further details), reducing emissions from non-road diesels used in underground applications are not within the scope of this project.

The estimated fuel consumption and PM emissions and the CBA findings presented in this section only relate to non-road diesels used at open-cut rather than underground coal mines (except for surface equipment).

Fuel consumption and PM emissions have been forecast over the period from 2012 to 2030 for non-road diesels at the 58 EPA-licensed coal mines that completed the EPA survey (EPA, 2013b) (see Section 7.1 for further details). Non-road diesel equipment (1) fleet size, (2) operating hours and (3) fuel consumption have been forecast to change according to fleet projection information provided in the survey and forecast coal production (EPA, 2013b). The forecast change in coal production at EPA-licensed coal mines from 2012 to 2030 is presented in Table 8-1.

Table 8-1: Forecast change in coal production at EPA-licensed coal mines from 2012 to 2030

Year	Forecast change in coal production (%)
2012	100
2013	112
2014	117
2015	123
2016	120
2017	123
2018	120
2019	121
2020	121
2021	120

Year	Forecast change in coal production (%)
2022	117
2023	115
2024	112
2025	104
2026	102
2027	96
2028	99
2029	94
2030	95

Forecast non-road diesel engine retrofit and equipment replacement options over the period from 2012 to 2030 have been modelled for each of the 58 coal mines that completed the survey as follows:

- **business as usual (BAU)** – replacement equipment has the same emissions certification as existing equipment
- **in-service non-road diesel retrofit** – the cumulative operating time (hours) for each engine are estimated and compared against the engine operating life (hours). Retrofits are timed to coincide with the first scheduled engine rebuild on or after the implementation year selected and replacement equipment has the same emissions certification as existing equipment
- **new replacement non-road diesels** - the cumulative operating time (hours) for each piece of equipment are estimated and compared against the equipment operating life (hours). Replacements are timed to coincide with the first scheduled equipment replacement on or after the implementation year selected.

8.1.1 Fuel consumption model

Non-road diesel fuel consumption has been estimated using equipment type, population, engine power rating and operating time in combination with load and transient adjustment factors within the *NONROAD2008a Model* (USEPA, 2009b) methodology. A summary of the EPA-licensed coal mine equipment fleet specification and activity data from the survey (EPA, 2013b) is presented in Section 7.2.4. Non-road diesel fuel consumption has been estimated for two reasons:

- **validate fuel consumption** – this confirms whether the engine power rating, engine brake specific fuel consumption (BSFC), operating time, load factor and transient adjustment factor data are sound. This step adds rigour to the subsequent emissions estimation model
- **estimate operating costs** – this determines the incremental change in fuel consumption associated with new replacement non-road diesels and retrofit exhaust aftertreatment equipment for in-service non-road diesels.

The annual diesel consumed by non-road diesels in surface applications at the 58 coal mines that completed the survey (EPA, 2013b) has been estimated using a model developed for this project. The annual diesel consumed by non-road diesels has been estimated at 919,327 kL/year or 99% of coal mine premises-wide fuel consumption in surface applications, which is reported to be 930,080 kL/year (EPA, 2013b). A linear regression of the estimated equipment vs. reported total premises-wide diesel consumption for surface equipment at EPA-licensed coal mines is shown in Figure 8-1. The linear regression exhibits a robust relationship with a coefficient of determination R^2 of 0.96. Although one coal mine data point is an outlier (estimated 154,855 kL/year), it is consistent with the coal mine's reported total diesel consumption in individual equipment (EPA, 2013b).

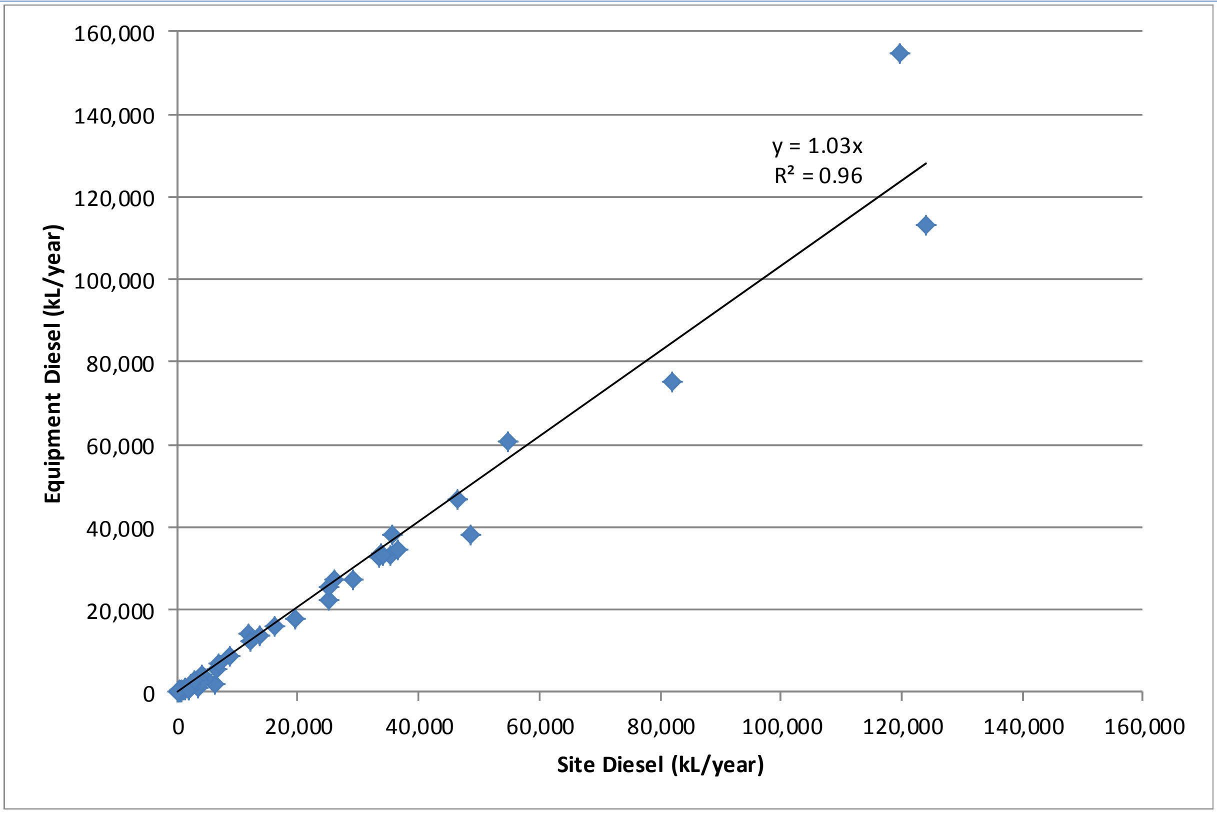

Figure 8-1: Estimated equipment vs. reported premises-wide diesel consumption for surface equipment at EPA-licensed coal mines in 2012

Fuel consumption has been forecast over the period from 2012 to 2030 for non-road diesels at the 58 EPA-licensed coal mines that completed the EPA survey (EPA, 2013b) (see Section 7.1 for further details). Non-road diesel fuel consumption has been forecast to change according to fleet projection information provided in the survey and forecast coal production (EPA, 2013b) (refer to Section 8.1 for further details). The BAU forecast diesel consumption for surface equipment at EPA-licensed coal mines from 2012 to 2030 is shown in Figure 8-2.

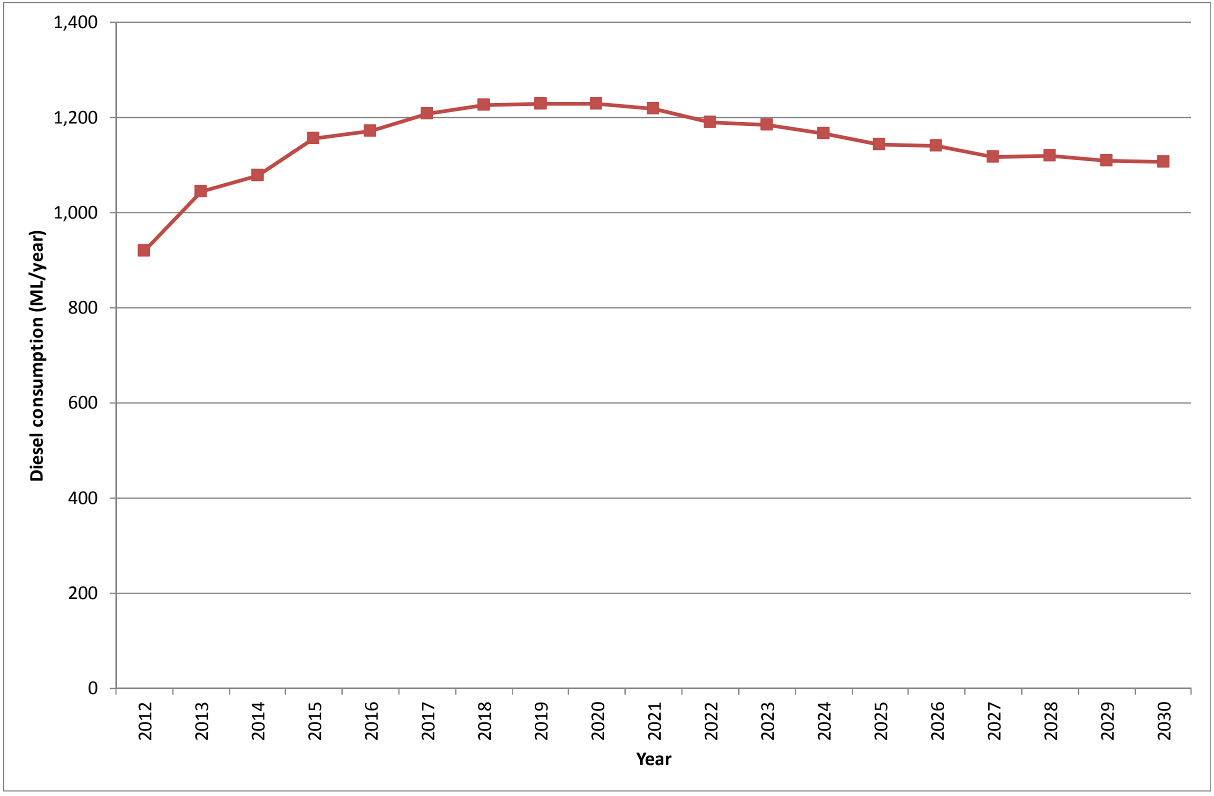

Figure 8-2: Business as usual forecast diesel consumption for surface equipment at EPA-licensed coal mines from 2012 to 2030

At EPA-licensed coal mines, BAU diesel consumption in 2012 has been estimated to be 919 ML/year, increasing to 1,229 ML/year in 2020 and then steadily declining to 1,106 ML/year by 2030.

8.1.2 Emissions model

Exhaust emissions from non-road diesels at coal mines have been estimated using equipment population, age, emission certification (e.g. US Tier 0, Tier 1, Tier 2, Tier 3 & Tier 4) and activity data in combination with emission, load, transient adjustment and deterioration factors within the *NONROAD2008a Model* (USEPA, 2009b) methodology. The PM_{10} and $PM_{2.5}$ exhaust emission factors for each piece of non-road diesel equipment used in surface application at the 58 EPA-licensed coal mines that completed the survey (EPA, 2013b) have been calculated using Equation 2:

$$EF_{adj} = EF_{steady\ state} \times TAF \times DF \times S_{PMadj}$$ **Equation 2**

where:

EF_{adj} is the adjusted PM emission factor in grams per kiloWatt.hour (g/Hp.hr)

$EF_{steady\ state}$ is the emission factor (g/Hp.hr) at zero engine hours under the certification steady state test cycle. This is based on certification test data were available

TAF is the transient adjustment factor which accounts for the impact of transient operation in typical real world operation relative to the steady state certification test

DF is the deterioration factor to model the increase in emissions with engine age and wear

S_{PMadj} is an adjustment factor to account for in-service diesel sulfur content, which is different to the sulfur content on which $EF_{steady\ state}$ are based

Exhaust emission factors have been adjusted according to the fuel sulfur content used at NSW coal mines from the survey (EPA, 2013b) (refer to Section 7.2.2 for further details). Over 99% of diesel consumed by EPA-licensed coal mines has a sulfur content of ≤ 10 ppm and complies with the *Fuel Standard (Automotive Diesel) Determination 2001*, while less than 1% of diesel consumed has a sulfur content of 50 – 500 ppm. The zero-hour steady state $PM_{2.5}$ emission factors by equipment description/horsepower range and US emissions certification are presented in Table 8-2. These emission factors incorporate adjustments to account for the impact of transient operation (TAF) and an in-service diesel sulfur content of 10 ppm (S_{PMadj}) but do not include deterioration resulting from engine wear (DF), although this is incorporated on an equipment specific basis in the emissions model.

Table 8-2: Zero-hour steady state $PM_{2.5}$ emission factors by equipment description/ horsepower range and US emissions certification

Equipment description-HP	$PM_{2.5}$ emission factor (g/Hp.hr)					
	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4i	Tier 4f
Dsl - Aerial Lifts-25-50	1.4397	0.5570	0.5937	0.5937	0.1825	0.0160
Dsl - Air Compressors-25-50	0.6831	0.2369	0.2736	0.2736	0.1825	0.0160
Dsl - Bore/Drill Rigs-100-175	0.3044	0.1880	0.1241	0.1629	0.0072	0.0072
Dsl - Bore/Drill Rigs-175-300	0.3044	0.1589	0.0756	0.0950	0.0072	0.0072
Dsl - Bore/Drill Rigs-300-600	0.3044	0.1104	0.0756	0.0950	0.0072	0.0072
Dsl - Bore/Drill Rigs-600-750	0.3044	0.1298	0.0756	0.0950	0.0072	0.0072
Dsl - Bore/Drill Rigs-750-1000	0.3044	0.1007	0.0755	0.0755	0.0651	0.0249
Dsl - Bore/Drill Rigs-1000-1200	0.3044	0.1007	0.0755	0.0755	0.0646	0.0244
Dsl - Bore/Drill Rigs-1200-2000	0.3044	0.1007	0.0756	0.0756	0.0652	0.0251
Dsl - Cranes-175-300	0.3044	0.1589	0.0756	0.0950	0.0072	0.0072
Dsl - Crawler Tractor/Dozers-175-300	0.3917	0.2171	0.1046	0.1628	0.0070	0.0070
Dsl - Crawler Tractor/Dozers-300-600	0.3917	0.1589	0.1047	0.1629	0.0072	0.0072
Dsl - Crawler Tractor/Dozers-600-750	0.3917	0.1783	0.1047	0.1629	0.0072	0.0072
Dsl - Crawler Tractor/Dozers-750-1000	0.3917	0.1492	0.1047	0.1047	0.0652	0.0250
Dsl - Excavators-25-50	0.8577	0.3145	0.3512	0.3512	0.1825	0.0160
Dsl - Excavators-50-75	0.7704	0.4697	0.2251	0.3706	0.1825	0.0160
Dsl - Excavators-75-100	0.7704	0.4697	0.2251	0.4148	0.0070	0.0070
Dsl - Excavators-100-175	0.3917	0.2462	0.1629	0.2599	0.0072	0.0072
Dsl - Excavators-175-300	0.3917	0.2171	0.1047	0.1629	0.0072	0.0072
Dsl - Excavators-300-600	0.3917	0.1589	0.1047	0.1629	0.0072	0.0072
Dsl - Excavators-600-750	0.3917	0.1783	0.1047	0.1629	0.0072	0.0072

Equipment description-HP	$PM_{2.5}$ emission factor (g/Hp.hr)					
	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4i	Tier 4f
Dsl - Excavators-750-1000	0.3917	0.1492	0.1046	0.1046	0.0651	0.0249
Dsl - Excavators-1000-1200	0.3917	0.1492	0.1047	0.1047	0.0652	0.0251
Dsl - Excavators-1200-2000	0.3917	0.1492	0.1047	0.1047	0.0652	0.0250
Dsl - Excavators-2000-3000	0.3917	0.1492	0.1047	0.1047	0.0652	0.0250
Dsl - Forklifts-25-50	0.8577	0.3145	0.3512	0.3512	0.1825	0.0160
Dsl - Forklifts-50-75	0.7712	0.4705	0.2259	0.3714	0.1833	0.0263
Dsl - Forklifts-75-100	0.7716	0.4709	0.2264	0.4160	0.0236	0.0236
Dsl - Forklifts-100-175	0.3924	0.2469	0.1635	0.2605	0.0155	0.0155
Dsl - Graders-100-175	0.3917	0.2462	0.1628	0.2598	0.0071	0.0071
Dsl - Graders-175-300	0.3917	0.2171	0.1047	0.1629	0.0071	0.0071
Dsl - Graders-300-600	0.3917	0.1589	0.1047	0.1629	0.0071	0.0071
Dsl - Graders-600-750	0.3917	0.1783	0.1047	0.1629	0.0072	0.0072
Dsl - Off-highway Trucks-100-175	0.3917	0.2462	0.1629	0.2599	0.0072	0.0072
Dsl - Off-highway Trucks-175-300	0.3917	0.2171	0.1047	0.1629	0.0072	0.0072
Dsl - Off-highway Trucks-300-600	0.3917	0.1589	0.1047	0.1629	0.0072	0.0072
Dsl - Off-highway Trucks-600-750	0.3917	0.1783	0.1047	0.1629	0.0072	0.0072
Dsl - Off-highway Trucks-750-1000	0.3917	0.1492	0.1046	0.1046	0.0651	0.0250
Dsl - Off-highway Trucks-1000-1200	0.3917	0.1492	0.1047	0.1047	0.0652	0.0251
Dsl - Off-highway Trucks-1200-2000	0.3917	0.1492	0.1047	0.1047	0.0652	0.0250
Dsl - Off-highway Trucks-2000-3000	0.3917	0.1492	0.1047	0.1047	0.0652	0.0250
Dsl - Pumps-100-175	0.3044	0.1880	0.1241	0.1629	0.0072	0.0072
Dsl - Pumps-300-600	0.3044	0.1104	0.0756	0.0950	0.0072	0.0072
Dsl - Rollers-25-50	0.8577	0.3145	0.3512	0.3512	0.1825	0.0160
Dsl - Rollers-100-175	0.3917	0.2462	0.1629	0.2599	0.0072	0.0072
Dsl - Rollers-175-300	0.3917	0.2171	0.1047	0.1629	0.0072	0.0072
Dsl - Rubber Tire Loaders-25-50	0.8601	0.3169	0.3536	0.3536	0.1849	0.0480
Dsl - Rubber Tire Loaders-50-75	0.7710	0.4703	0.2257	0.3712	0.1831	0.0243
Dsl - Rubber Tire Loaders-75-100	0.7710	0.4703	0.2257	0.4154	0.0147	0.0147
Dsl - Rubber Tire Loaders-100-175	0.3917	0.2462	0.1629	0.2599	0.0072	0.0072
Dsl - Rubber Tire Loaders-175-300	0.3919	0.2173	0.1048	0.1630	0.0097	0.0097

Equipment description-HP	**$PM_{2.5}$ emission factor (g/Hp.hr)**					
	Tier 0	**Tier 1**	**Tier 2**	**Tier 3**	**Tier 4i**	**Tier 4f**
Dsl - Rubber Tire Loaders-300-600	0.3917	0.1589	0.1046	0.1628	0.0071	0.0071
Dsl - Rubber Tire Loaders-600-750	0.3917	0.1783	0.1046	0.1628	0.0071	0.0071
Dsl - Rubber Tire Loaders-750-1000	0.3917	0.1492	0.1046	0.1046	0.0651	0.0250
Dsl - Rubber Tire Loaders-1000-1200	0.3917	0.1492	0.1047	0.1047	0.0652	0.0251
Dsl - Rubber Tire Loaders-1200-2000	0.3917	0.1492	0.1046	0.1046	0.0651	0.0250
Dsl - Rubber Tire Loaders-2000-3000	0.3917	0.1492	0.1047	0.1047	0.0652	0.0251
Dsl - Scrapers-175-300	0.3917	0.2171	0.1046	0.1628	0.0071	0.0071
Dsl - Scrapers-300-600	0.3917	0.1589	0.1047	0.1629	0.0072	0.0072
Dsl - Signal Boards/Light Plants-25-50	0.6831	0.2369	0.2736	0.2736	0.1825	0.0160
Dsl - Skid Steer Loaders-25-50	1.4397	0.5570	0.5937	0.5937	0.1825	0.0160
Dsl - Skid Steer Loaders-50-75	1.2845	0.8092	0.3997	0.6325	0.1825	0.0160
Dsl - Skid Steer Loaders-75-100	1.2876	0.8123	0.4028	0.6784	0.0485	0.0485
Dsl - Sweepers/Scrubbers-100-175	0.3044	0.1880	0.1241	0.1629	0.0072	0.0072
Dsl - Tractors/Loaders/Backhoes-75-100	1.2845	0.8092	0.3997	0.6753	0.0070	0.0070
Dsl - Tractors/Loaders/Backhoes-100-175	0.6827	0.4499	0.2987	0.4539	0.0072	0.0072
Dsl - Welders-50-75	1.2845	0.8092	0.3997	0.6325	0.1825	0.0160

An engine's rated power is the maximum power it is designed to produce at the rated speed. Since engines normally operate at a variety of speeds and loads, operation at rated power for extended periods is rare. To take into account the effect of operation over a wide range of conditions (e.g. idle, partial load and transient operation), a load factor (LF) based on data from the survey (EPA, 2013b) (refer to Section 7.2.4 for further details) has been used to determine the average proportion of rated power used.

Transient adjustment factors (TAF) from the *NONROAD2008a Model* (USEPA, 2009b) have been applied to emission factors to account for in-use (i.e. transient) operation and better represent the operational behaviour of the equipment.

Deterioration factors (DF) have been applied to account for deterioration of emission performance over time. Deterioration refers to the degradation of an engine's exhaust emissions performance over its lifetime due to normal use and/or misuse (i.e. tampering or neglect). Engine deterioration usually leads to a loss of combustion efficiency and increased oil consumption, which result in increased exhaust emissions. The amount of deterioration depends on an engine's design, production quality and technology type. Other factors may also affect deterioration, such as the equipment application, usage patterns and how it is stored and maintained. Cumulative engine use and engine life data from the survey (EPA, 2013b) (refer to Section 7.2.4 for further details) have been used to calculate DF using the *NONROAD2008a Model* methodology. Annual PM_{10} and $PM_{2.5}$ exhaust emissions for each piece of non-road diesel equipment used in surface application at the 58 EPA-licensed coal mines that completed the survey (EPA, 2013b) have been calculated using:

$$PM_{annual} = EF_{adj} \times EnginePower \times LF \times Hours/yr \qquad \textbf{Equation 3}$$

where:

PM_{annual} is the total annual PM emissions in grams

EF_{adj} is the adjusted PM emission factor in grams per kiloWatt.hour (g/Hp.hr)

$EnginePower$ is the equipment total rated power in kilowatts

LF is the load factor in %, being the annual average operating power as a % of maximum power

$Hours/yr$ is the total annual operating hours.

$PM_{2.5}$ emissions have been forecast over the period from 2012 to 2030 for non-road diesels at the 58 EPA-licensed coal mines that completed the EPA survey (EPA, 2013b) (see Section 7.1 for further details). Non-road diesel fuel consumption has been forecast to grow according to fleet projection information provided in the survey and forecast coal production (EPA, 2013b) (refer to Section 8.1 for further details). The business as BAU forecast $PM_{2.5}$ for surface equipment at EPA-licensed coal mines from 2012 to 2030 is shown in Figure 8-3.

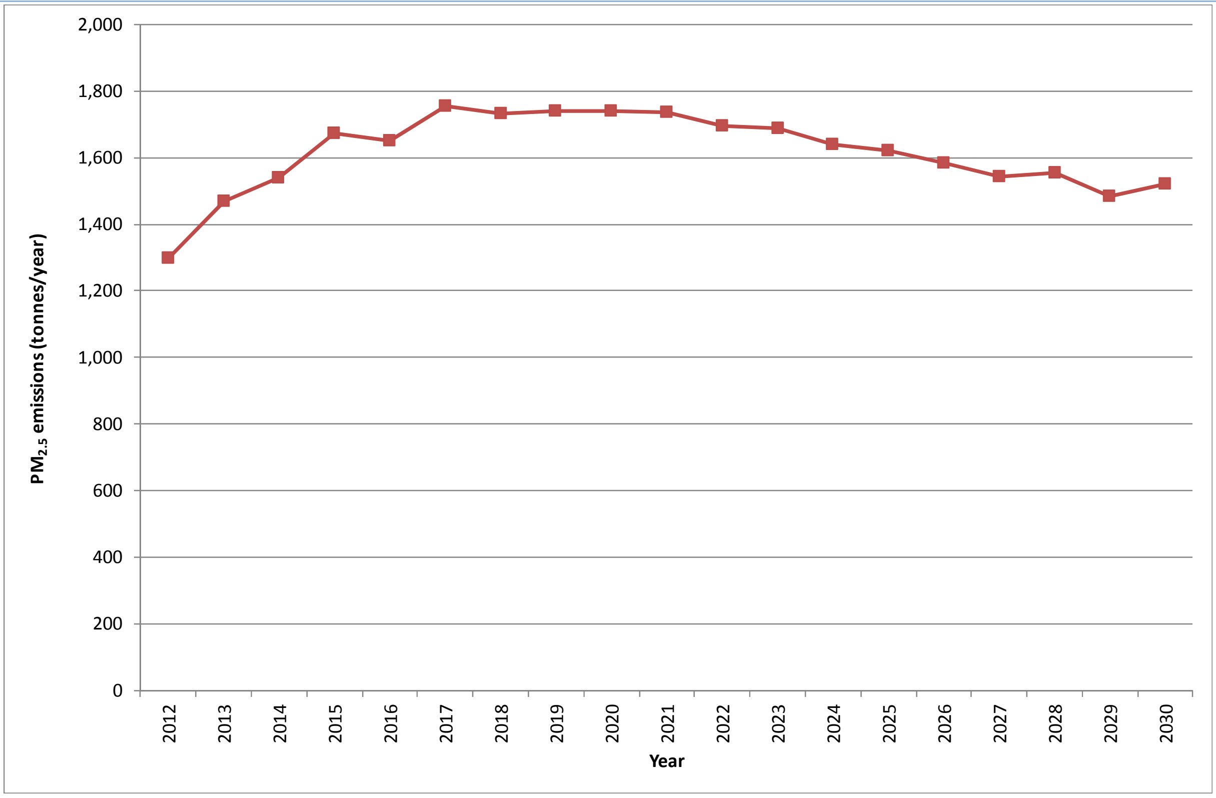

Figure 8-3: Business as usual forecast $PM_{2.5}$ emissions for surface equipment at EPA-licensed coal mines from 2012 to 2030

At EPA-licensed coal mines, BAU $PM_{2.5}$ emissions in 2012 have been estimated to be 1,298 tonne/year, increasing to 1,754 tonne/year in 2017 and then steadily declining to 1,520 tonne/year by 2030.

In order to benchmark the existing performance of NSW coal mines, $PM_{2.5}$ emissions have been estimated for non-road diesels in 2012 at the 58 EPA-licensed coal mines that completed the EPA survey (EPA, 2013b) by assuming the following:

- **business as usual (BAU)** – the fleet is composed of equipment with existing emissions certification
- **in-service non-road diesel exhaust aftertreatment retrofit** – the fleet is composed of equipment with existing emissions certification and either DOC, pDFP, passive DPF or active DPF are installed
- **new replacement non-road diesels** - the fleet is replaced with equipment with either US Tier 0, Tier 1, Tier 2, Tier 3 or Tier 4 emissions certification.

Annual $PM_{2.5}$ emissions from non-road diesels at NSW coal mines are about 44% lower than US Tier 0 performance (2,325 tonnes/year (US Tier 0) vs. 1,300 tonnes/year (BAU)). However, NSW coal mines have significant scope to further reduce annual $PM_{2.5}$ emissions from non-road diesels by about 90% (1,300 tonnes/year (BAU) vs. 135 tonnes/year (US Tier 4)). The annual BAU $PM_{2.5}$ emissions from non-road diesels at NSW coal mines in 2012 have been compared with the various retrofit and replacement options and these are shown in Figure 8-4.

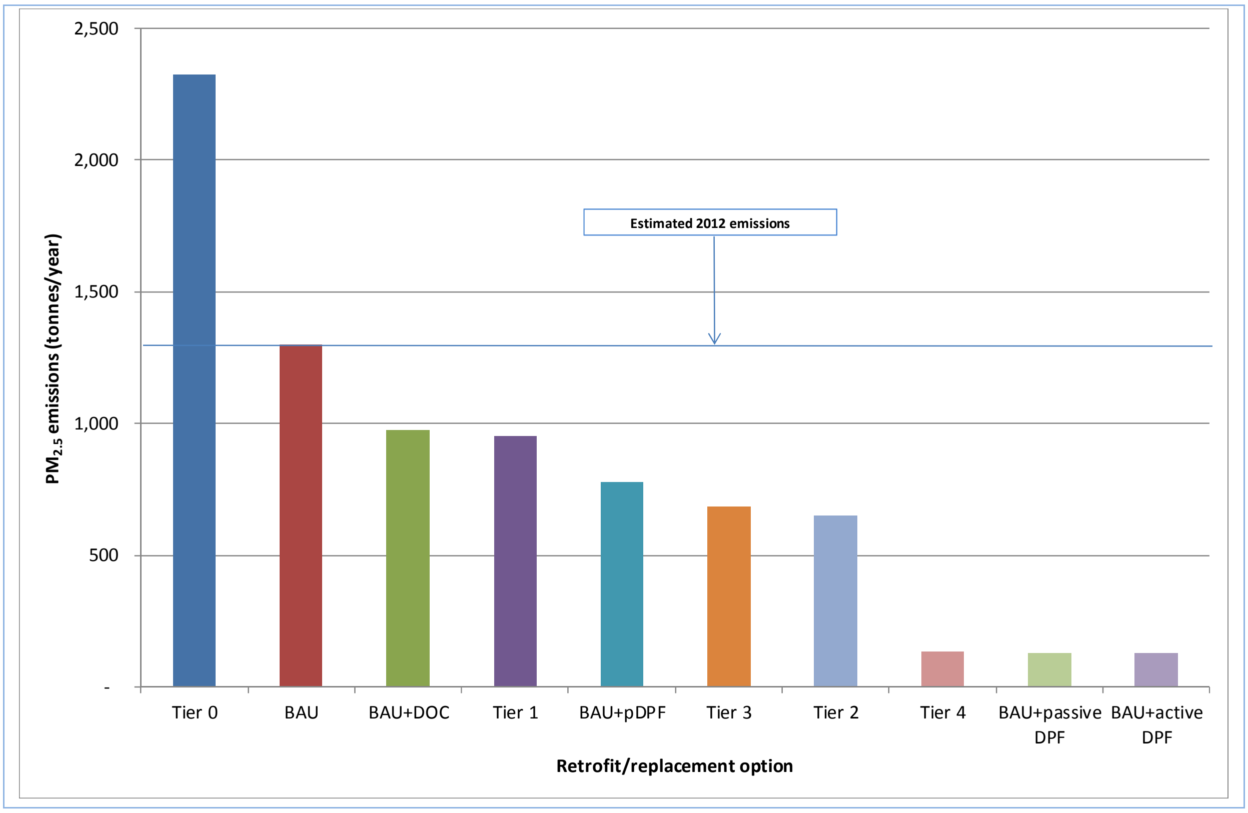

Figure 8-4: Business as usual vs. retrofit and replacement $PM_{2.5}$ emissions for surface equipment at EPA-licensed coal mines in 2012

8.1.3 Cost benefit analysis methodology

The CBA methodology is consistent with NSW Treasury economic appraisal guidance (NSW Treasury, 2007a, 2007b & 2007c). To estimate the net benefits of reducing PM emissions from non-road diesels at coal mines, the CBA accounts for the $PM_{2.5}$ unit damage costs and the capital, maintenance and operating costs for new replacement non-road diesels and retrofit exhaust aftertreatment equipment for in-service non-road diesels.

$PM_{2.5}$ unit damage costs and the capital costs for non-road diesels will continue to rise in line with economic growth.

The CBA assumes the change in $PM_{2.5}$ unit damage costs is consistent with the long term growth in Gross Domestic Product (GDP) of 2%, which is based on the findings of the PAEHolmes international review and the UK DEFRA air quality damage cost guidance (refer to Section 2.4 for further details). The CBA assumes a discount rate of 7%, which is based on NSW Treasury economic appraisal guidance (refer to Section 2.4 for further details).

The maintenance and operating costs for non-road diesels are proportional to forecast diesel prices (refer to Section 5.4, Section 5.5, Section 6.5 & Section 0 for further details).

The CBA is for the period from 2012 to 2030 or a project life of 19 years and all costs and benefits are reported in 2012 AUD.

8.2 Fuel Consumption and Emissions Model and Cost Benefit Analysis Assumptions

This section summarises the assumptions used in the fuel consumption and emissions model and the CBA, including unit damage costs for PM and equipment capital, maintenance and operating costs for new replacement non-road diesels and retrofit exhaust aftertreatment equipment for in-service non-road diesels.

8.2.1 Unit damage costs

Since the CBA findings refer to the 2012 base year, the unit damage costs in future calendar years (from 2013 to 2030) have been adjusted to the 2012 calendar year. The compound interest formula has been used to express 2013 to 2030 calendar year unit damage costs as 2012 calendar year present value (PV) estimates. For each significant urban area (SUA) in NSW, the unit damage costs in future years have been adjusted to 2012 calendar year PV estimates by accounting for (1) population change, (2) willingness to pay for health care and (3) the time value of money using Equation 4.

$$UDC_n = UDC_{2012} \text{ x } (POP_n/POP_{2012}) \text{ x } (1+GDP/100)^{(n-2012)}/(1+DR/100)^{(n-2012)} \qquad \textbf{Equation 4}$$

where:
UDC = Unit damage cost in AUD
POP = Population in each significant urban area (SUA) in NSW
GDP = Long term growth rate in Gross Domestic Product (2%)
DR = Discount rate (7%)
n = calendar year from 2012 to 2030

The 2012 to 2030 calendar year unit damage costs for $PM_{2.5}$ in 2012 AUD by SUA in NSW, which have been used in this project, are presented in Table 8-3 (refer to Section 2.4 for further details).

Table 8-3: 2012 to 2030 unit damage costs for $PM_{2.5}$ by significant urban area (SUA) in NSW (2012 AUD)

SUA name	Damage cost/tonne of $PM_{2.5}$ (2012 AUD)																		
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Sydney	290,515	281,626	272,932	264,437	256,139	248,379	240,785	233,359	226,101	219,011	211,935	205,043	198,331	191,799	185,445	179,241	173,213	167,356	161,669
Central Coast	154,569	148,843	143,314	137,976	132,825	127,988	123,314	118,797	114,432	110,217	106,092	102,112	98,273	94,569	90,997	87,515	84,159	80,927	77,812
Wollongong	133,483	128,087	122,905	117,926	113,145	108,833	104,677	100,672	96,813	93,094	89,446	85,936	82,559	79,310	76,184	73,144	70,223	67,415	64,716
Port Macquarie	123,936	119,609	115,416	111,353	107,418	103,479	99,674	95,998	92,448	89,021	85,489	82,092	78,827	75,687	72,669	69,672	66,796	64,037	61,390
Forster - Tuncurry	113,839	110,082	106,427	102,873	99,420	95,518	91,764	88,152	84,678	81,336	77,926	74,656	71,523	68,519	65,640	62,849	60,176	57,616	55,163
Newcastle - Maitland	113,969	110,330	106,782	103,325	99,958	96,601	93,339	90,172	87,096	84,112	81,203	78,383	75,649	72,999	70,432	67,921	65,491	63,139	60,865
Goulburn	95,195	91,066	87,116	83,335	79,718	76,626	73,649	70,783	68,024	65,368	62,687	60,114	57,645	55,275	53,001	50,819	48,725	46,715	44,787
Ballina	92,610	89,055	85,629	82,330	79,151	75,913	72,805	69,821	66,957	64,209	61,459	58,827	56,306	53,892	51,581	49,302	47,124	45,042	43,051
Lismore	91,026	87,007	83,164	79,491	75,980	72,623	69,414	66,346	63,414	60,610	57,778	55,078	52,504	50,051	47,712	45,442	43,281	41,222	39,261
Griffith	89,273	83,665	78,386	73,417	68,742	64,965	61,391	58,009	54,809	51,781	48,917	46,207	43,644	41,219	38,926	36,757	34,705	32,765	30,931
Ulladulla	87,152	83,510	80,018	76,670	73,460	70,454	67,568	64,798	62,140	59,588	57,095	54,704	52,412	50,215	48,109	46,064	44,104	42,228	40,430
Cessnock	84,787	81,919	79,133	76,429	73,805	71,334	68,933	66,601	64,336	62,137	59,984	57,896	55,873	53,912	52,012	50,141	48,332	46,582	44,890
Wagga Wagga	78,175	75,147	72,231	69,424	66,721	64,159	61,690	59,313	57,022	54,817	52,755	50,766	48,848	46,999	45,215	43,459	41,768	40,141	38,574
Orange	73,007	70,154	67,409	64,768	62,226	59,780	57,426	55,163	52,985	50,891	48,876	46,939	45,076	43,284	41,562	39,888	38,280	36,735	35,251
Nelson Bay - Corlette	63,629	62,000	60,383	58,783	57,200	55,359	53,565	51,818	50,118	48,463	46,842	45,267	43,736	42,250	40,807	39,371	37,979	36,632	35,328
Dubbo	53,302	51,061	48,913	46,854	44,881	43,072	41,335	39,666	38,062	36,522	35,042	33,622	32,257	30,947	29,688	28,441	27,246	26,101	25,003
Kurri Kurri - Weston	51,699	49,950	48,252	46,603	45,003	43,496	42,032	40,610	39,229	37,889	36,576	35,303	34,069	32,873	31,715	30,574	29,470	28,403	27,372
Grafton	49,017	46,781	44,647	42,611	40,667	38,962	37,327	35,761	34,259	32,819	31,368	29,981	28,656	27,388	26,177	24,982	23,841	22,752	21,713
Batemans Bay	48,536	46,836	45,189	43,594	42,049	40,410	38,833	37,315	35,854	34,448	33,063	31,733	30,454	29,226	28,046	26,874	25,751	24,674	23,641
Nowra-	47,164	45,193	43,304	41,492	39,755	38,128	36,566	35,067	33,629	32,248	30,898	29,605	28,364	27,175	26,036	24,929	23,868	22,853	21,880

SUA name	Damage cost/tonne of $PM_{2.5}$ (2012 AUD)																		
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Bomaderry																			
St Georges Basin - Sanctuary Point	47,164	45,193	43,304	41,492	39,755	38,128	36,566	35,067	33,629	32,248	30,898	29,605	28,364	27,175	26,036	24,929	23,868	22,853	21,880
Tamworth	46,293	44,504	42,782	41,123	39,526	38,025	36,579	35,184	33,840	32,545	31,287	30,076	28,910	27,787	26,705	25,641	24,619	23,635	22,690
Bathurst	44,586	43,194	41,835	40,508	39,214	37,936	36,691	35,480	34,301	33,156	32,029	30,935	29,873	28,843	27,844	26,865	25,916	24,997	24,108
Taree	38,905	37,226	35,618	34,080	32,607	31,224	29,898	28,628	27,411	26,246	25,059	23,927	22,845	21,812	20,826	19,868	18,955	18,084	17,252
Albury - Wodonga	38,030	36,529	35,085	33,697	32,361	31,065	29,819	28,622	27,472	26,367	25,333	24,338	23,381	22,461	21,575	20,716	19,889	19,095	18,332
Coffs Harbour	37,010	35,557	34,159	32,814	31,520	30,300	29,125	27,994	26,905	25,856	24,783	23,753	22,766	21,819	20,910	20,014	19,156	18,334	17,548
Singleton	37,095	35,719	34,391	33,109	31,871	30,652	29,478	28,346	27,256	26,206	25,175	24,183	23,229	22,312	21,429	20,565	19,735	18,937	18,171
Broken Hill	30,151	28,315	26,584	24,953	23,417	22,096	20,847	19,666	18,551	17,496	16,520	15,596	14,723	13,898	13,117	12,363	11,652	10,979	10,344
Lithgow	29,523	28,089	26,725	25,427	24,192	23,084	22,026	21,017	20,055	19,136	18,242	17,389	16,577	15,802	15,064	14,360	13,689	13,049	12,439
Bowral - Mittagong	23,623	22,675	21,764	20,888	20,047	19,222	18,431	17,672	16,944	16,245	15,555	14,895	14,262	13,656	13,075	12,509	11,967	11,448	10,952
Armidale	23,849	23,106	22,380	21,672	20,981	20,190	19,428	18,692	17,983	17,300	16,652	16,027	15,425	14,843	14,282	13,742	13,220	12,718	12,233
Morisset - Cooranbong	18,435	17,645	16,889	16,164	15,471	14,851	14,256	13,683	13,134	12,605	12,093	11,601	11,128	10,675	10,239	9,816	9,411	9,022	8,649
Parkes	13,260	12,640	12,050	11,487	10,950	10,466	10,003	9,561	9,138	8,734	8,337	7,957	7,595	7,250	6,920	6,614	6,321	6,041	5,774
Muswellbrook	13,390	12,889	12,405	11,938	11,487	11,053	10,634	10,230	9,841	9,466	9,094	8,736	8,392	8,061	7,743	7,437	7,142	6,859	6,586
Camden Haven	8,676	8,373	8,079	7,795	7,519	7,244	6,977	6,720	6,471	6,231	5,984	5,746	5,518	5,298	5,087	4,877	4,676	4,483	4,297
Not in any Significant Urban Area (NSW)	370	355	341	327	314	301	289	277	265	254	244	233	224	214	205	196	188	180	172

8.2.2 Exhaust emission control effectiveness

This section summarises the exhaust emission control effectiveness assumptions used for new replacement non-road diesels and retrofit exhaust aftertreatment equipment for in-service non-road diesels.

8.2.2.1 Retrofit equipment

The emission reduction effectiveness for the range of diesel exhaust aftertreatment equipment available for heavy duty diesel retrofit are summarised in Table 8-4 (refer to Section 6.1 for further details).

Table 8-4: Summary of exhaust aftertreatment emission control effectiveness

Exhaust Aftertreatment Equipment	PM Reduction assumed in Cost Benefit Analysis
Diesel Oxidation Catalyst (DOC)	25%
Partial Diesel Particulate Filter (pDPF)	40%
Catalysed Diesel Particulate Filter (CDPF)	90%
Oxidation Catalyst plus Diesel Particulate Filter (CRT type DPF)	90%

8.2.2.2 New equipment

The PM emissions of new equipment were modelled using the standard emission factors used in the USEPA *NONROAD2008a Model (*USEPA, 2009b). These implicitly incorporate the OEM engine exhaust emission control effectiveness needed to meet the US Tier 0 to Tier 4 emissions standards (refer to Section 8.1.2 for further details).

8.2.3 Capital costs

This section summarises the equipment capital cost assumptions used for new replacement non-road diesels and retrofit exhaust aftertreatment equipment for in-service non-road diesels.

8.2.3.1 Retrofit equipment

Exhaust Control Industries, IAC Colpro, Mammoth Equipment & Exhausts, Johnson Matthey and Umicore provided retrofit diesel exhaust aftertreatment equipment information and cost data for the supply and installation of various types of technologies on a range of mining equipment. The average costs of the various retrofit exhaust aftertreatment equipment technologies provided by all suppliers were used to estimate equipment costs as a function of engine power. The formulae for average cost of retrofit exhaust aftertreatment equipment are presented in Table 8-5 (refer to Section 6.4 for further details).

Table 8-5: Average cost of retrofit exhaust aftertreatment equipment (2012 AUD)

Exhaust Aftertreatment Equipment	Cost = (m x Hp + b)/1.024	
	m	b
Diesel Oxidation Catalyst (DOC)	9.95	2,024
Partial Diesel Particulate Filter (pDPF)	20.86	3,756
Passive Diesel Particulate Filter (DPF)	28.71	6,278
Active Diesel Particulate Filter (DPF)	48.06	8,924

8.2.3.2 New equipment

The NSW Environment Protection Authority (EPA) Information Report for the introduction of national non-road diesel emission standards includes information from a wide range of Australian suppliers and representatives of non-road diesel equipment original equipment manufacturers (OEM). The data received from Australian suppliers is in the form of incremental retail costs relative to uncertified engines (US Tier 0) for a bare engine (plus required aftertreatment) that meets US Tier 2 to Tier 4 emission standards. The formulae for average cost of engines for each US Tier emission standard vs. engine power are presented in Table 8-6 (refer to Section 6.4 for further details).

Table 8-6: US Tier 2, Tier 3 & Tier 4 compliant incremental engine costs relative to Tier 0 & Tier 1 compliant engines (2012 AUD)

Tier	Incremental Engine Costs Cost = m x Horsepower (Hp) + b	
	m	b
Tier 0	0	0
Tier 1	0	0
Tier 2	3.86	174
Tier 3	14.88	1,224
Tier 4	70.38	1,544

8.2.3.3 Adblue storage tank and dispenser equipment

The total cost to equip all NSW open-cut coal mines with Adblue storage tanks and dispensers in order to cater for a fleet made up of entirely US Tier 4 non-road diesels has been estimated to be $3.0 million (2012 AUD) (refer to Section 5.5.3 for further details). This cost is based on a maximum fleet weighted average Adblue consumption of 3.5% of diesel consumption (refer to Section 5.5.2 for further details).

On a per coal mine basis, the total one-off investment ranges from about $40,000 to $400,000. This is about 0.3% of the annual diesel cost for larger coal mines (> 200,000 litres diesel per week) and up to 2% to 3% of the annual diesel cost for smaller coal mines (< 40,000 litres diesel per week).

8.2.4 Maintenance costs

This section summarises the equipment maintenance cost assumptions used for new replacement non-road diesels and retrofit exhaust aftertreatment equipment for in-service non-road diesels.

8.2.4.1 Retrofit equipment

In retrofit exhaust aftertreatment equipment applications, incremental maintenance costs are largely incurred when cleaning DPF, while DOC and pDPF are essentially maintenance free.

Diesel particulate filter cleaning costs from the USEPA Tier 4 Final Regulatory Analysis have been used. These incremental annual maintenance costs are expressed as percentages of diesel cost and are presented in Table 8-7 (refer to Section 6.5 for further details).

Table 8-7: Maintenance costs for DPF

Horsepower (Hp)	DPF maintenance costs expressed as % diesel cost
< 25 Hp	0.00
25 ≤ Hp < 50	3.43
50 ≤ Hp < 75	2.39
75 ≤ Hp < 175	1.19
175 ≤ Hp < 300	0.30
300 ≤ Hp < 600	0.15
600 ≤ Hp < 750	0.15
≥ 750 Hp	0.30

8.2.4.2 New equipment

For US Tier 4 compliant engines, incremental maintenance costs are largely incurred when cleaning DPF and servicing/replacing CCV filters. Since there is no substantial change in engine architecture and exhaust aftertreatment technologies between US Tier 2 and Tier 3 compliant engines when compared to US Tier 0 and 1, incremental maintenance costs have not been applied to US Tier 3 or earlier. Data from the USEPA Tier 4 Final Regulatory Analysis has been used. These incremental annual maintenance costs are expressed as percentages of diesel cost and are presented in Table 8-8 (refer to Section 5.4 for further details).

Table 8-8: Maintenance costs for US Tier 4 compliant engines

Horsepower (Hp)	Maintenance costs expressed as % diesel cost		
	DPF maintenance	CCV maintenance	Net maintenance
< 25 Hp	0.00	0.00	0.00
25 ≤ Hp < 50	3.43	0.00	3.43
50 ≤ Hp < 75	2.39	0.15	2.54
75 ≤ Hp < 175	1.19	0.45	1.64
175 ≤ Hp < 300	0.30	0.30	0.60
300 ≤ Hp < 600	0.15	0.15	0.30
600 ≤ Hp < 750	0.15	0.30	0.45
≥ 750 Hp	0.00	0.30	0.30

8.2.5 Operating costs

This section summarises the equipment operating cost assumptions used for new replacement non-road diesels and retrofit exhaust aftertreatment equipment for in-service non-road diesels.

The diesel price in future years have been forecast from the baseline 2012 calendar year diesel price of 1.13 AUD using US Energy Information Administration (EIA) forecast petroleum product prices and these are presented in Table 8-9 (refer to Section 5.5.1 for further details).

Table 8-9: Forecast coal mine diesel price (2012 AUD)

Year	Diesel Price (2012 AUD)	Year	Diesel Price (2012 AUD)
2012	$1.13	2022	$1.19
2013	$1.05	2023	$1.20
2014	$1.03	2024	$1.22
2015	$1.04	2025	$1.24
2016	$1.06	2026	$1.25
2017	$1.08	2027	$1.27
2018	$1.10	2028	$1.29
2019	$1.12	2029	$1.30
2020	$1.14	2030	$1.32
2021	$1.16		

8.2.5.1 Retrofit equipment

In retrofit exhaust aftertreatment equipment applications, incremental operating costs are incurred when using active DPF generation, while DOC and pDPF have no additional operating costs.

When operating conditions maintain sufficient exhaust temperatures, the DPF is continually self-regenerating and this is known as passive regeneration. On very infrequent occasions, an active self-regeneration is required to remove a build-up of PM in the DPF, due to insufficient exhaust temperatures. Additional diesel consumption of 0.1% is quoted by original equipment manufacturers (OEM) when using DPF and this is presented for relevant engine horsepower ranges in Table 8-10 (refer to Section 0 for further details).

Table 8-10: Operating costs for DPF

Horsepower (Hp)	DPF operating costs expressed as % diesel cost*
< 25 Hp	0.0
25 ≤ Hp < 50	0.1
50 ≤ Hp < 75	0.1
75 ≤ Hp < 175	0.1
175 ≤ Hp < 300	0.1
300 ≤ Hp < 600	0.1
600 ≤ Hp < 750	0.1
≥ 750 Hp	0.1

8.2.5.2 New equipment

The estimated impacts of US Tier 0 to Tier 4 emission standards on fuel consumption in non-road diesel engines are presented in Table 8-11 (refer to Section 5.5.1 for further details).

Table 8-11: Fuel consumption impacts on US Tier 0 – Tier 4 compliant engines

Estimate Source	Relative Fuel Consumption (<560kW/>560kW)				
	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4f
Relative efficiency used in cost-benefit analysis	100%/100%	100%/100%	102%/102%	101.5%/-	98.5%/97.5%

The Adblue price for future years have been forecast from the baseline 2012 calendar year Adblue price of 0.78 AUD using US Energy Information Administration (EIA) forecast petroleum product prices and these are presented in Table 8-12 (refer to Section 5.5.2 for further details).

Table 8-12: Forecast coal mine Adblue price (2012 AUD)

Year	Adblue Price (2012 AUD)	Year	Adblue Price (2012 AUD)
2012	$0.78	2022	$0.82
2013	$0.80	2023	$0.83
2014	$0.79	2024	$0.85
2015	$0.72	2025	$0.86
2016	$0.73	2026	$0.87
2017	$0.75	2027	$0.88
2018	$0.76	2028	$0.89
2019	$0.78	2029	$0.90
2020	$0.79	2030	$0.91
2021	$0.80		

The estimated impacts of US Tier 4 emission standards on Adblue consumption in non-road diesel engines are presented for relevant engine horsepower ranges in Table 8-13 (refer to Section 5.5.2 for further details). For US Tier 4 compliant engines, SCR exhaust aftertreatment technology is likely to be used in 100% of 75 to 750 Hp class (Ecopoint Inc., 2013b; USEPA, 2004 & USEPA, 2012a) and 50% to 100% of greater than 750 Hp class (Ecopoint Inc., 2013b; USEPA, 2004 & USEPA, 2012a; Cummins Inc., 2012 & MTU, 2014) equipment. Adblue consumption equivalent to 2.5% (< 750 Hp) and 3 to 6% (≥ 750 Hp) of diesel consumption is quoted by OEMs. A fleet weighted average Adblue consumption of 1.4% to 3.5% of diesel consumption has been calculated for the NSW coal mining fleet reported in the survey of EPA-licensed coal mines (EPA, 2013b).

Table 8-13: Adblue consumption for US Tier 4 compliant engines

Horsepower (Hp)	Adblue consumption expressed as % diesel consumption*#
< 25 Hp	0
25 ≤ Hp < 50	0
50 ≤ Hp < 75	0
75 ≤ Hp < 175	2.5
175 ≤ Hp < 300	2.5
300 ≤ Hp < 600	2.5
600 ≤ Hp < 750	2.5
≥ 750 Hp	1.25 to 3.6

Horsepower (Hp)	Adblue consumption expressed as % diesel consumption*#
Fleet Weighted Average	**1.4 to 3.5**
*References NSW Environment Protection Authority (EPA) *Reducing Emissions from Non-Road Diesel Engines Information Report* (EPA Information Report) (EPA, 2014) http://parts.cat.com/parts/fluids/def http://www.cumminsfiltration.com/html/en/literature/product_literature/asia/additives.html http://www.dieselnet.com/news/2011/05cummins.php #For US Tier 4 compliant engines, SCR exhaust aftertreatment technology is likely to be used in 100% of 75 to 750 Hp class (Ecopoint Inc., 2013b; USEPA, 2004 & USEPA, 2012a) and 50% to 100% of greater than 750 Hp class (Ecopoint Inc., 2013b; USEPA, 2004 & USEPA, 2012a; Cummins Inc., 2012 & MTU, 2014) equipment	

8.3 Cost Benefit Analysis Options

The CBA has evaluated a number of retrofit, replacement and combined retrofit and replacement options for reducing non-road diesel exhaust emissions as follows:

- **business as usual (BAU)** – (1) equipment is replaced with equipment that has the existing emissions certification.

- **in-service non-road diesel exhaust aftertreatment retrofit** – retrofits are timed to coincide with the first available engine rebuild on or after the year ending 2014 and equipment is replaced with equipment that has the existing emissions certification. Retrofit diesel exhaust aftertreatment options evaluated include:
  - (2) diesel oxidation catalyst (DOC)
  - (3) partial diesel particulate filter (pDPF)
  - (4) passive DPF
  - (5) active DPF.

- **new replacement non-road diesels** - replacements are timed to coincide with the first available equipment replacement on or after the year ending 2017. The US emission standards evaluated include:
  - (6) US Tier 0, replaced with Tier 1. Tier 1 to Tier 4 equipment is replaced with the existing emissions certification
  - (7) US Tier 1 or less, replaced with Tier 2. Tier 2 to Tier 4 equipment is replaced with the existing emissions certification
  - (8) US Tier 2 or less, replaced with Tier 3. Tier 3 to Tier 4 equipment is replaced with the existing emissions certification
  - (9) US Tier 3 or less, replaced with Tier 4. Tier 4 equipment is replaced with the existing emissions certification.

- **combined retrofit and replacement** – retrofit and replacement options are combined and optimised. If a retrofit and replacement are scheduled for the same year, the equipment is replaced rather than retrofit. The combined options evaluated include:
  - (10) in-service retrofit with passive DPF combined with new replacement with US Tier 4.

8.3.1 Option 1 – BAU

Business as usual (BAU) $PM_{2.5}$ emissions and health costs over the period from 2012 to 2030 are presented in Table 8-14 and Figure 8-5. Since this is a BAU or 'do nothing' option, no costs are incurred and there are no benefits.

Table 8-14: Business as usual $PM_{2.5}$ emissions and health costs from 2012 to 2030

Metric	BAU-Actual certification
$PM_{2.5}$ emissions (tonnes)	30,661
Health cost - PV million (2012 AUD)	507

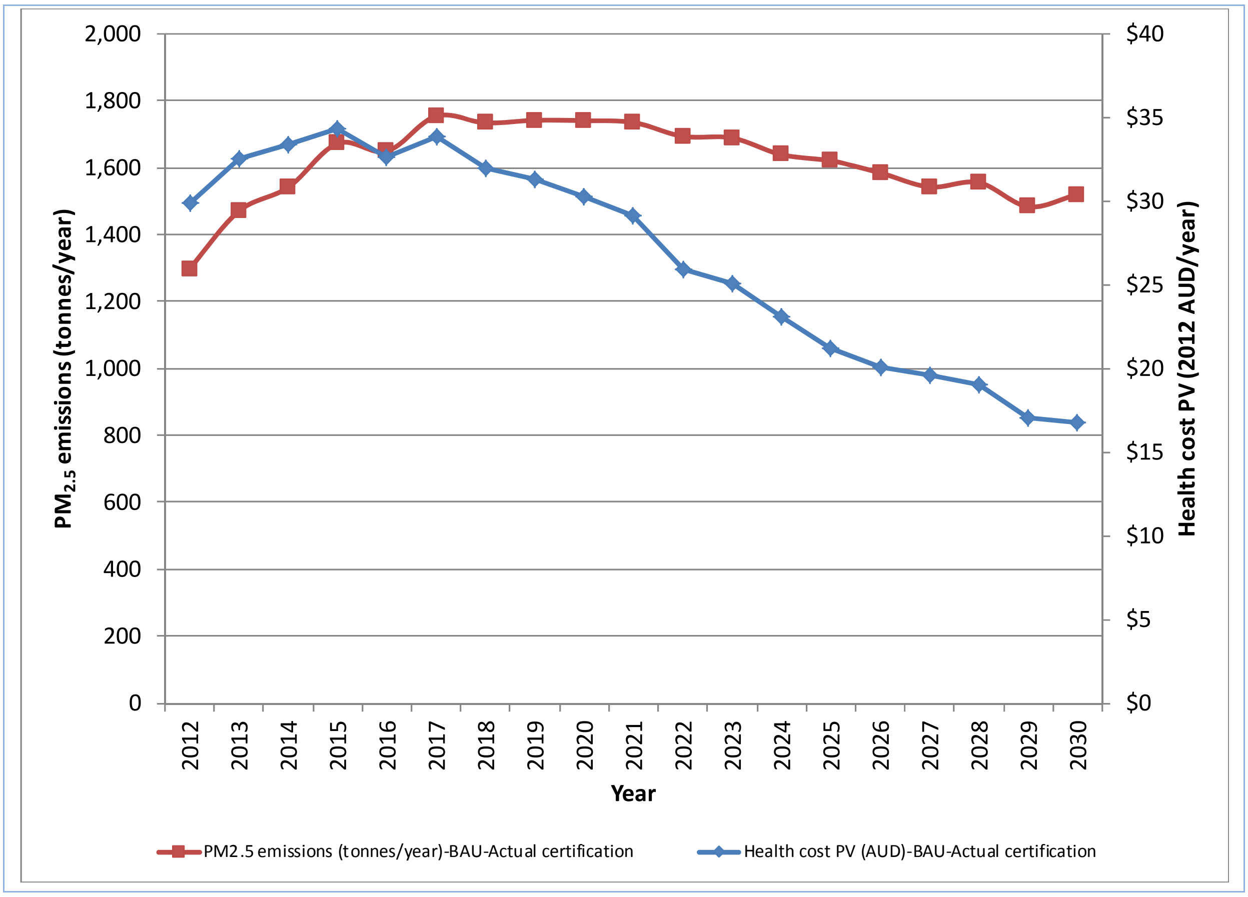

Figure 8-5: Business as usual $PM_{2.5}$ emissions and health costs from 2012 to 2030

8.3.2 Option 2 – Retrofit with DOC

Retrofit with DOC $PM_{2.5}$ emissions, costs and benefits over the period from 2012 to 2030 are presented in Table 8-15, Figure 8-6 and Figure 8-7. Capital costs have been estimated at 26 million (2012 AUD), while health benefits and net benefits have been estimated at 92 and 66 million (2012 AUD), respectively.

Table 8-15: Retrofit with DOC $PM_{2.5}$ emissions, costs and benefits from 2012 to 2030

Metric	BAU-Actual certification	Actual certification-Minimum retrofit year-ending-2014-Retrofit control efficiency (%)-25-DOC
$PM_{2.5}$ emissions (tonnes)	30,661	24,638
$PM_{2.5}$ reduction (tonnes)	0	6,023
Health cost - PV million (2012 AUD)	507	415
Capital cost - PV million (2012 AUD)	0	26
Operating cost - PV million (2012 AUD)	0	0
Maintenance cost - PV million (2012 AUD)	0	0
Health benefit - PV million (2012 AUD)	0	92
Net benefit - NPV million (2012 AUD)	0	66

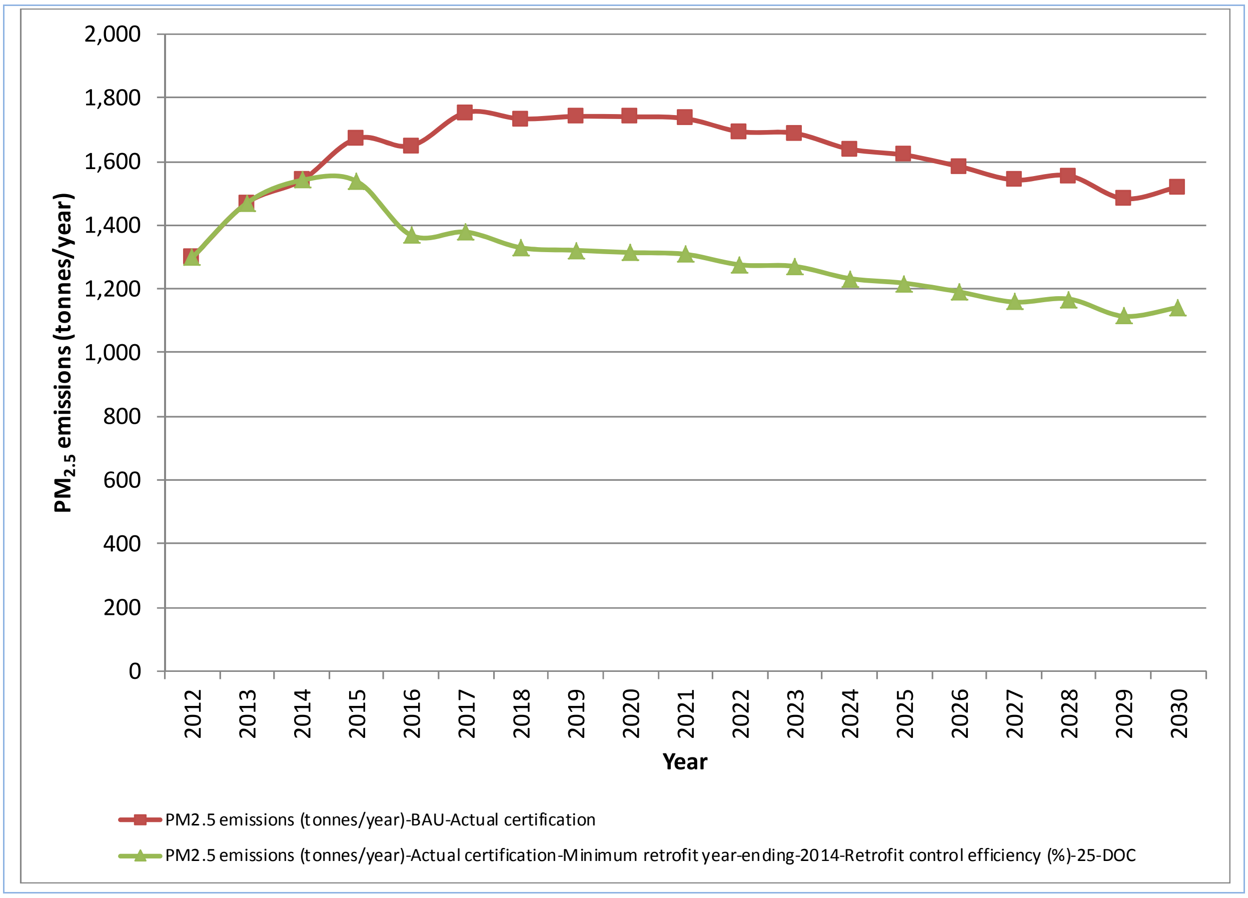

Figure 8-6: Retrofit with DOC $PM_{2.5}$ emissions from 2012 to 2030

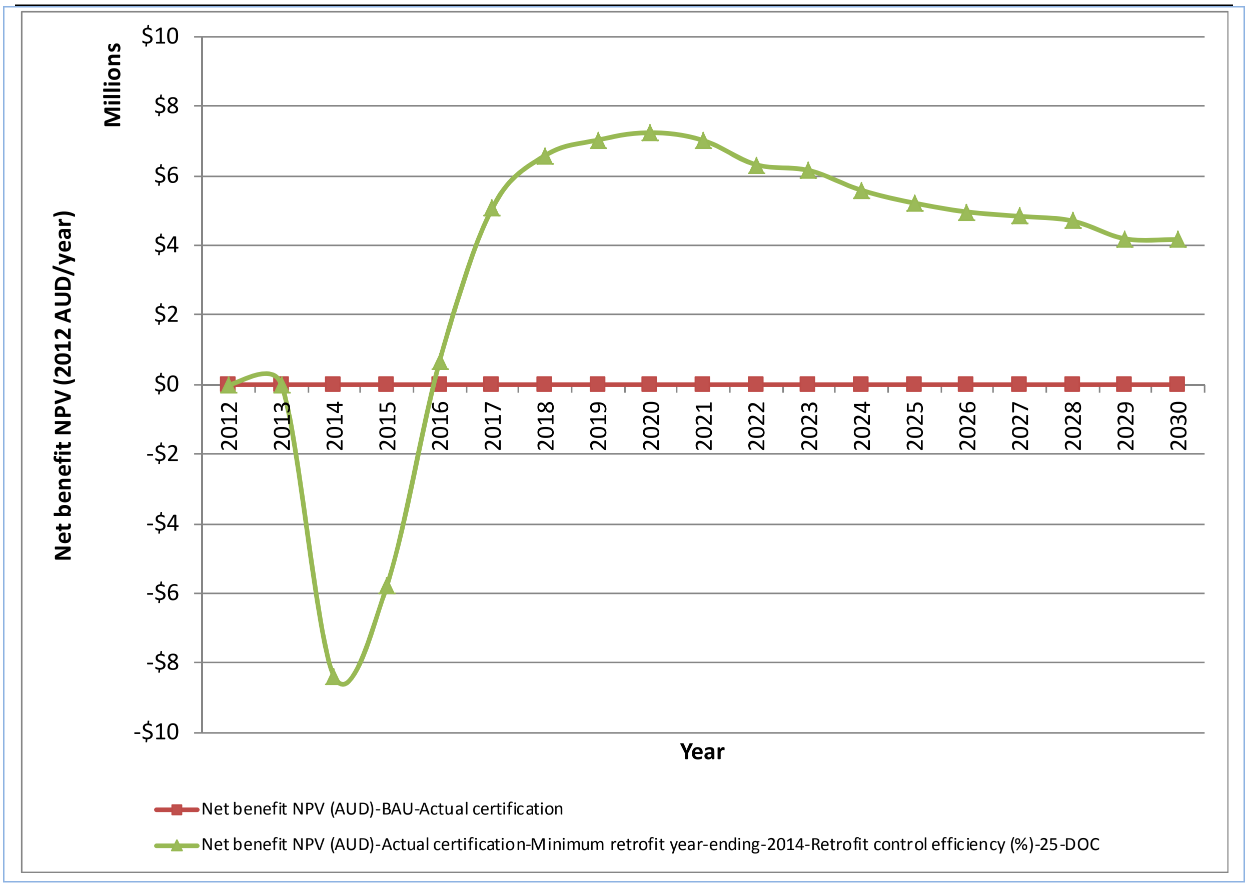

Figure 8-7: Retrofit with DOC net benefit from 2012 to 2030

8.3.3 Option 3 – Retrofit with pDPF

Retrofit with pDPF $PM_{2.5}$ emissions, costs and benefits over the period from 2012 to 2030 are presented in Table 8-16, Figure 8-8 and Figure 8-9. Capital costs have been estimated at 54 million (2012 AUD), while health benefits and net benefits have been estimated at 147 and 93 million (2012 AUD), respectively.

Table 8-16: Retrofit with pDPF $PM_{2.5}$ emissions, costs and benefits from 2012 to 2030

Metric	BAU-Actual certification	Actual certification-Minimum retrofit year-ending-2014-Retrofit control efficiency (%)-40-PDPF
$PM_{2.5}$ emissions (tonnes)	30,661	21,024
$PM_{2.5}$ reduction (tonnes)	0	9,637
Health cost - PV million (2012 AUD)	507	360
Capital cost - PV million (2012 AUD)	0	54
Operating cost - PV million (2012 AUD)	0	0
Maintenance cost - PV million (2012 AUD)	0	0
Health benefit - PV million (2012 AUD)	0	147
Net benefit - NPV million (2012 AUD)	0	93

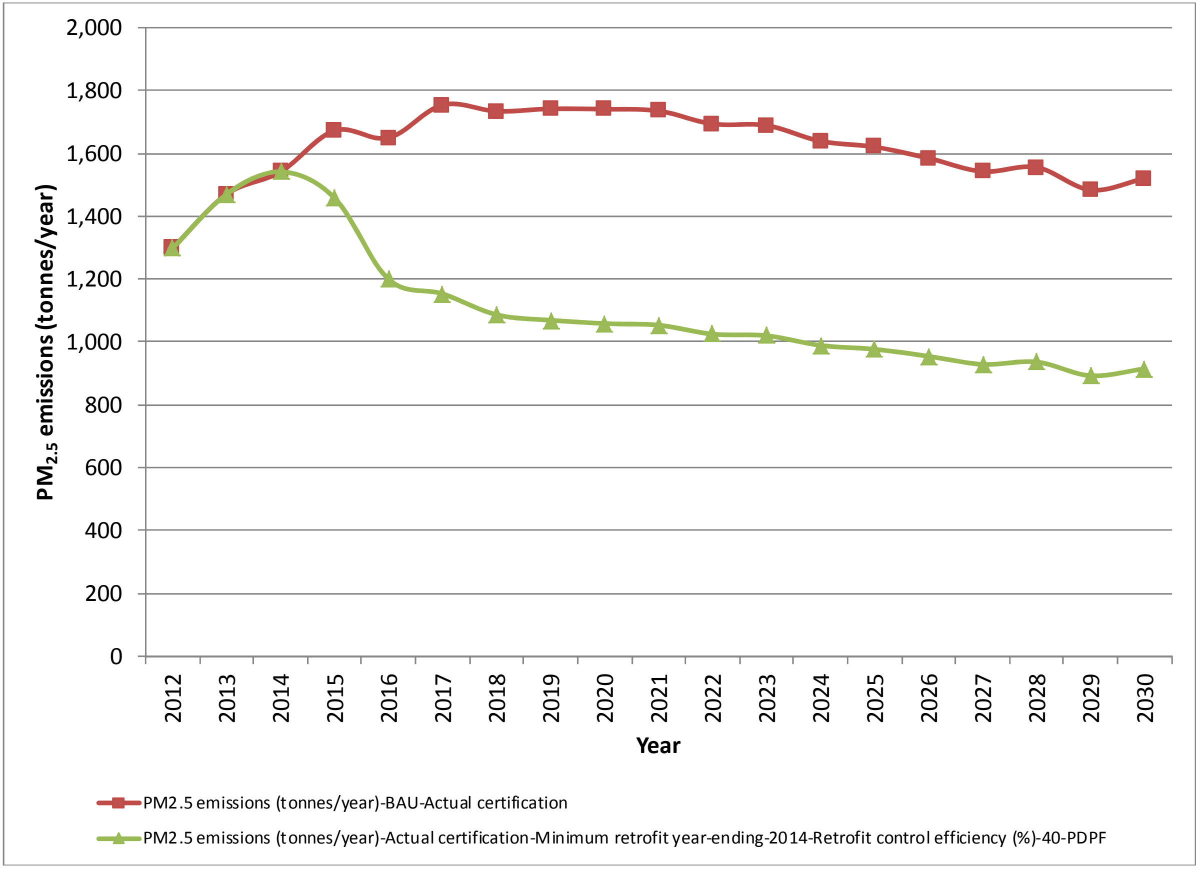

Figure 8-8: Retrofit with pDPF $PM_{2.5}$ emissions from 2012 to 2030

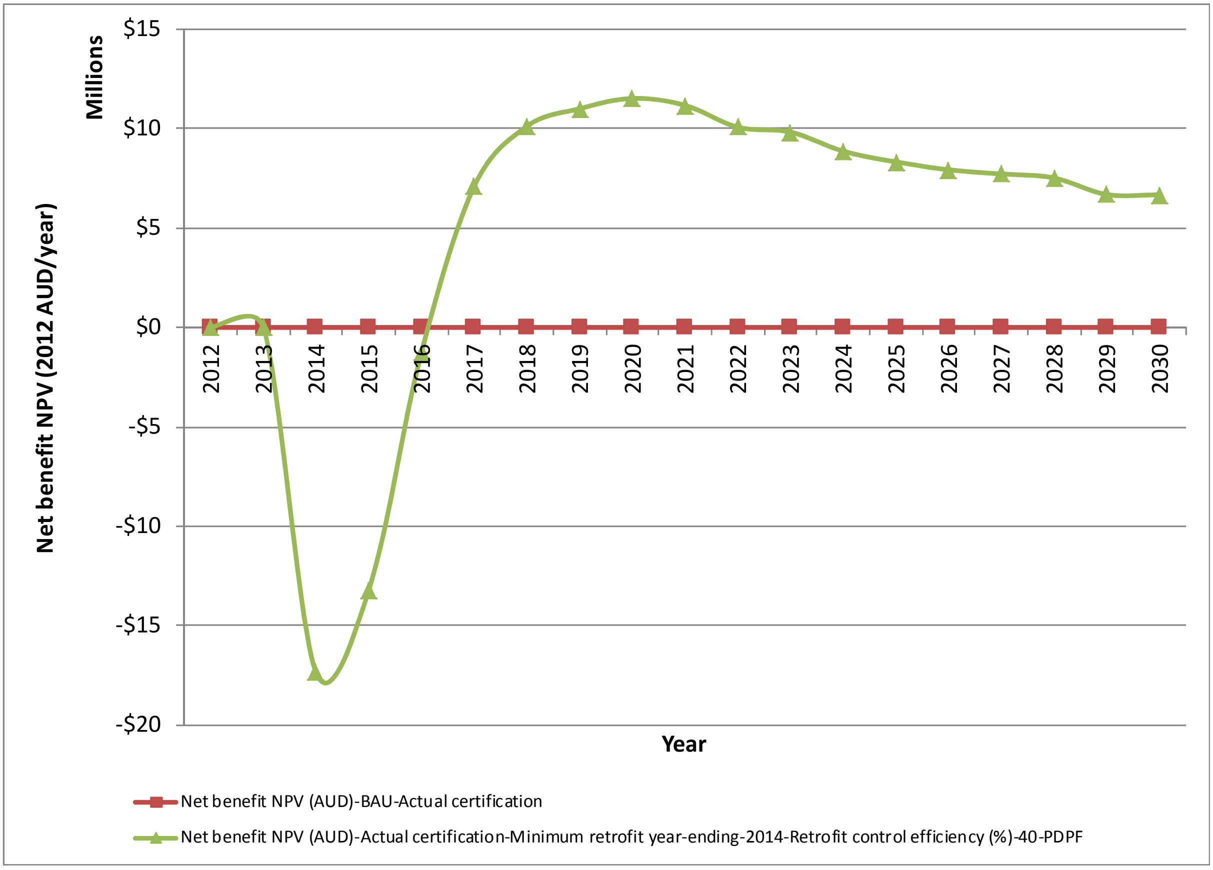

Figure 8-9: Retrofit with pDPF net benefit from 2012 to 2030

8.3.4 Option 4 – Retrofit with passive DPF

Retrofit with passive DPF $PM_{2.5}$ emissions, costs and benefits over the period from 2012 to 2030 are presented in Table 8-17, Figure 8-10 and Figure 8-11. Capital costs have been estimated at 76 million (2012 AUD), while health benefits and net benefits have been estimated at 331 and 220 million (2012 AUD), respectively. Maintenance costs have been estimated at 34 million (2012 AUD).

Table 8-17: Retrofit with passive DPF $PM_{2.5}$ emissions, costs and benefits from 2012 to 2030

Metric	BAU-Actual certification	Actual certification-Minimum retrofit year-ending-2014-Retrofit control efficiency (%)-90-FDPF w/o actv. rgn.
$PM_{2.5}$ emissions (tonnes)	30,661	8,977
$PM_{2.5}$ reduction (tonnes)	0	21,684
Health cost - PV million (2012 AUD)	507	176
Capital cost - PV million (2012 AUD)	0	76
Operating cost - PV million (2012 AUD)	0	0
Maintenance cost - PV million (2012 AUD)	0	34
Health benefit - PV million (2012 AUD)	0	331
Net benefit - NPV million (2012 AUD)	0	220

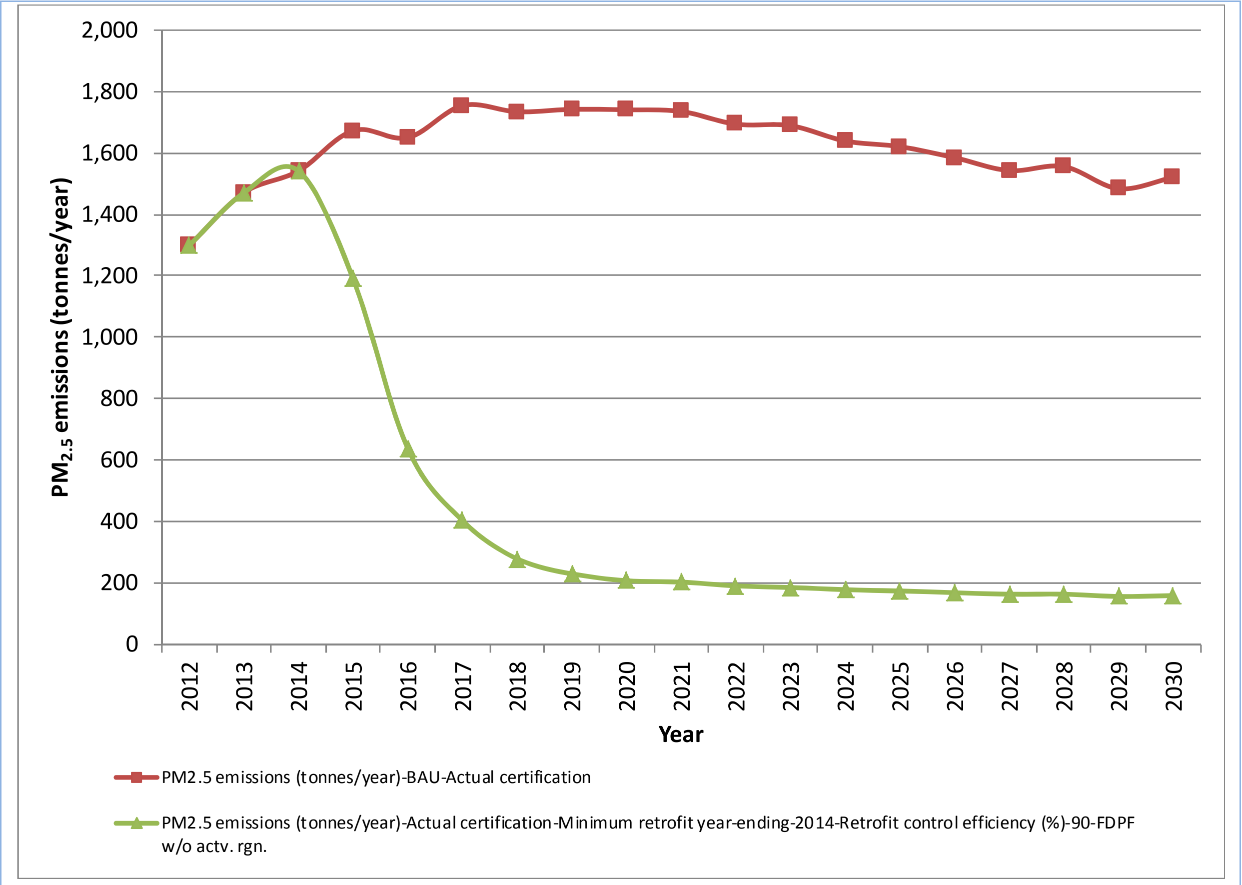

Figure 8-10: Retrofit with passive DPF $PM_{2.5}$ emissions from 2012 to 2030

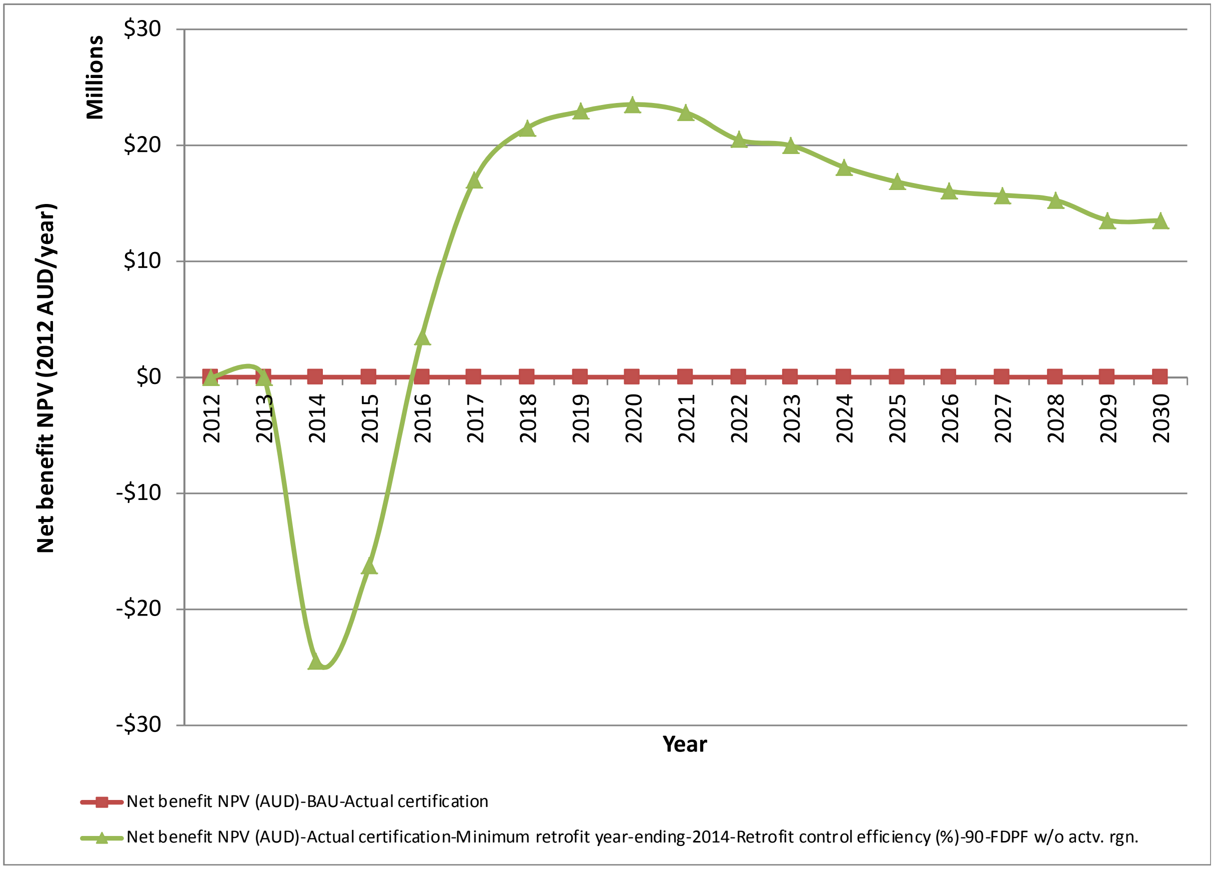

Figure 8-11: Retrofit with passive DPF net benefit from 2012 to 2030

8.3.5 Option 5 – Retrofit with active DPF

Retrofit with active DPF $PM_{2.5}$ emissions, costs and benefits over the period from 2012 to 2030 are presented in Table 8-18, Figure 8-12 and Figure 8-13. Capital costs have been estimated at 126 million (2012 AUD), while health benefits and net benefits have been estimated at 331 and 150 million (2012 AUD), respectively. Operating costs and maintenance costs have been estimated at 21 and 34 million (2012 AUD), respectively.

Table 8-18: Retrofit with active DPF $PM_{2.5}$ emissions, costs and benefits from 2012 to 2030

Metric	BAU-Actual certification	Actual certification-Minimum retrofit year-ending-2014-Retrofit control efficiency (%)-90-FDPF w/ actv. rgn.
$PM_{2.5}$ emissions (tonnes)	30,661	8,977
$PM_{2.5}$ reduction (tonnes)	0	21,684
Health cost - PV million (2012 AUD)	507	176
Capital cost - PV million (2012 AUD)	0	126
Operating cost - PV million (2012 AUD)	0	21
Maintenance cost - PV million (2012 AUD)	0	34
Health benefit - PV million (2012 AUD)	0	331
Net benefit - NPV million (2012 AUD)	0	150

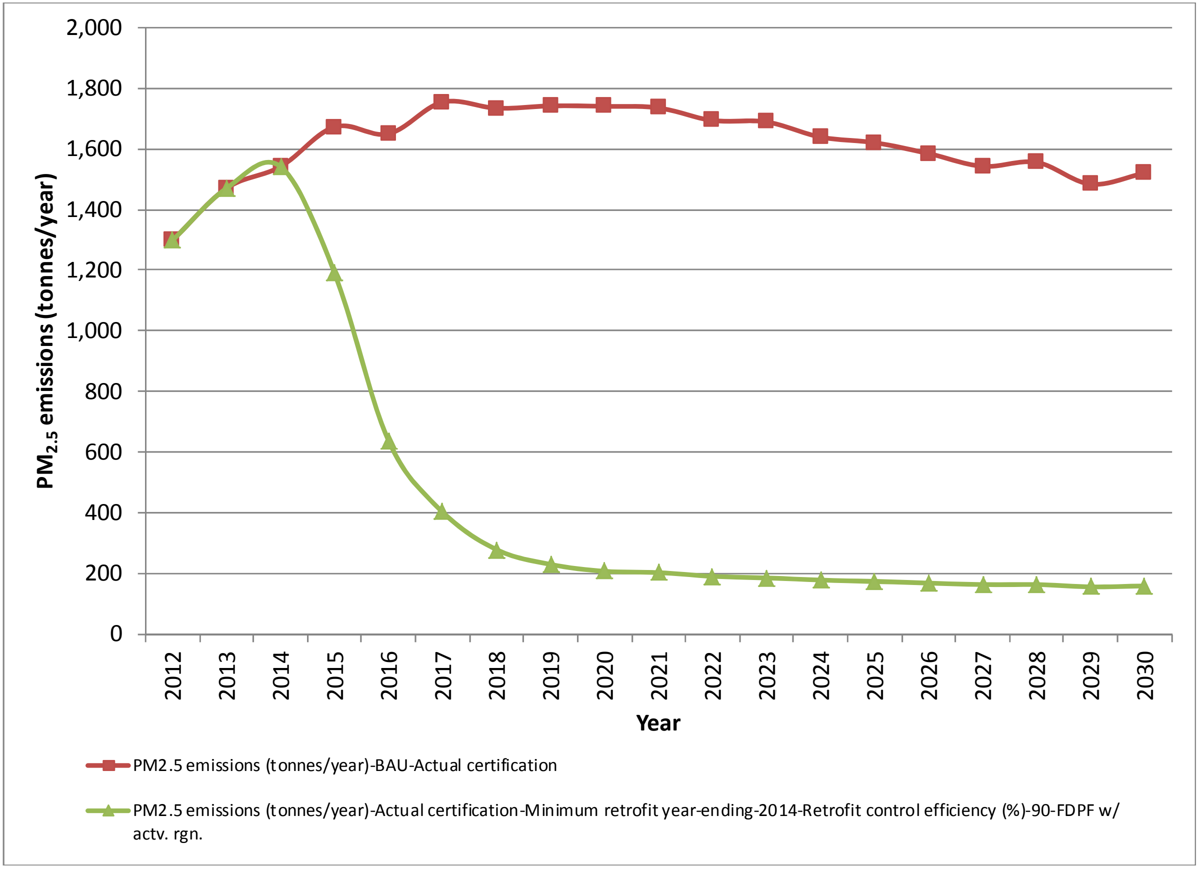

Figure 8-12: Retrofit with active DPF $PM_{2.5}$ emissions from 2012 to 2030

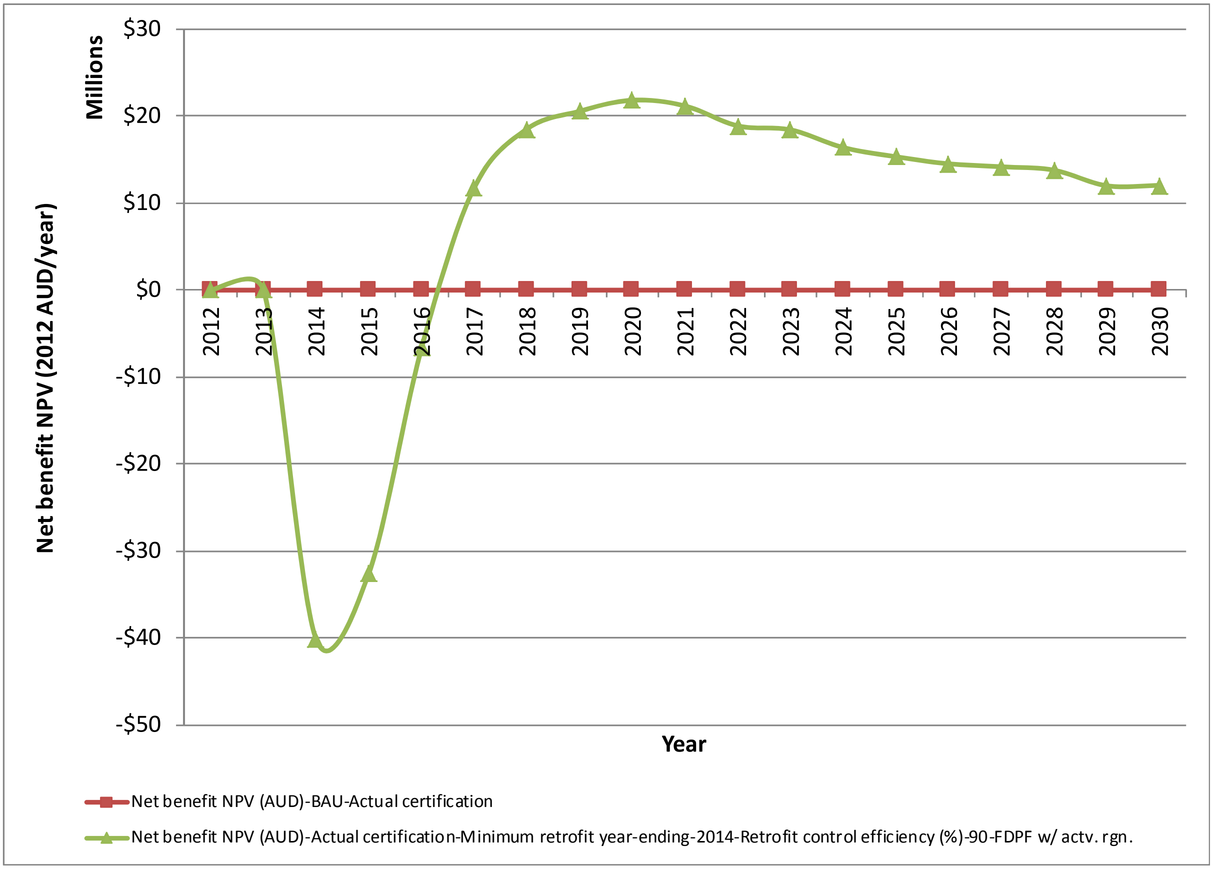

Figure 8-13: Retrofit with active DPF net benefit from 2012 to 2030

8.3.6 Option 6 – Replacement with US Tier 1

Replacement with US Tier 1 $PM_{2.5}$ emissions, costs and benefits over the period from 2012 to 2030 are presented in Table 8-19, Figure 8-14 and Figure 8-15. There are no capital costs, while health benefits and net benefits have been estimated at 46 million (2012 AUD).

Table 8-19: Replacement with Tier 1 $PM_{2.5}$ emissions, costs and benefits from 2012 to 2030

Metric	BAU-Actual certification	USEPA Tier 1-Minimum replacement year-ending-2017-Retrofit control efficiency (%)-0-NIL
$PM_{2.5}$ emissions (tonnes)	30,661	26,541
$PM_{2.5}$ reduction (tonnes)	0	4,120
Health cost - PV million (AUD)	507	461
Capital cost - PV million (AUD)	0	0
Operating cost - PV million (AUD)	0	0
Maintenance cost - PV million (AUD)	0	0
Health benefit - PV million (AUD)	0	46
Net benefit - NPV million (AUD)	0	46

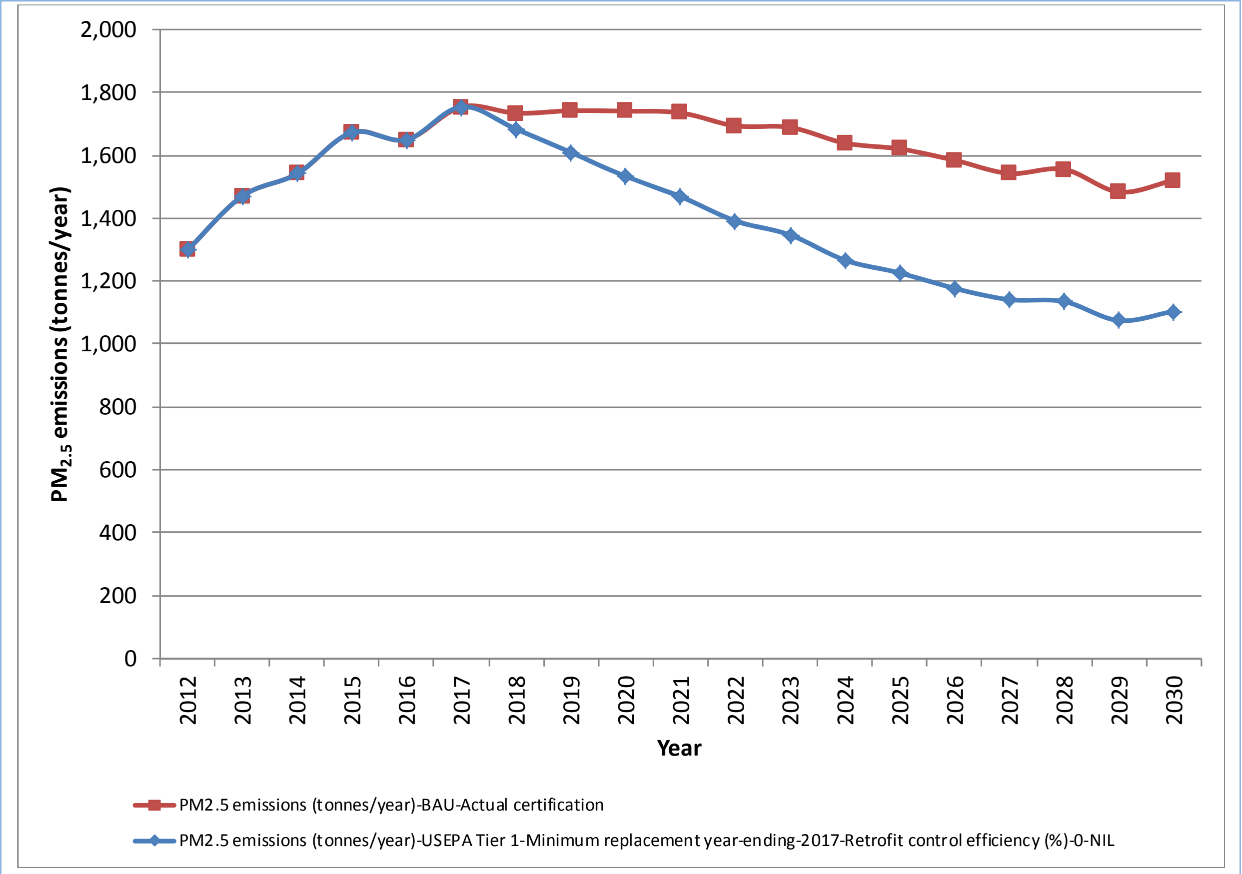

Figure 8-14: Replacement with Tier 1 $PM_{2.5}$ emissions from 2012 to 2030

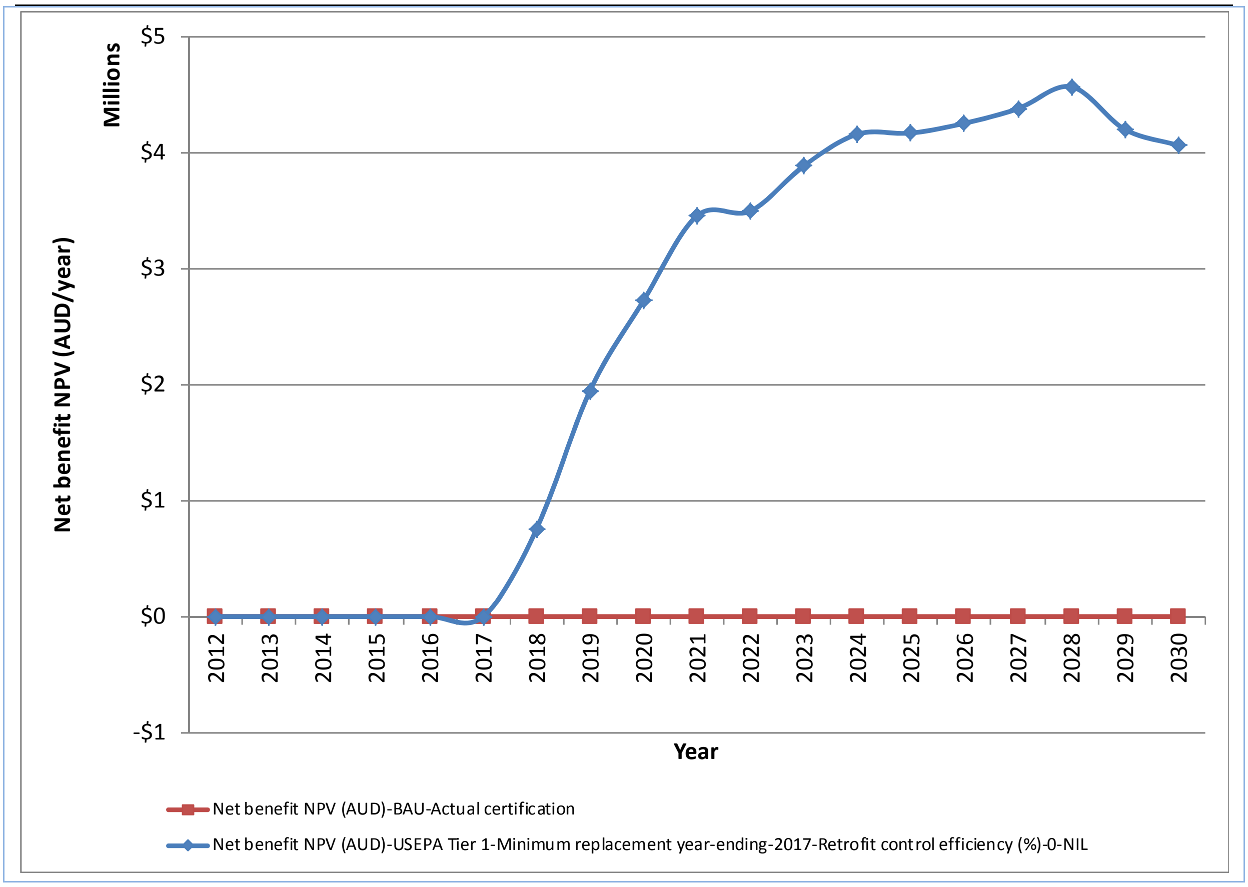

Figure 8-15: Replacement with Tier 1 net benefit from 2012 to 2030

8.3.7 Option 7 – Replacement with US Tier 2

Replacement with US Tier 2 $PM_{2.5}$ emissions, costs and benefits over the period from 2012 to 2030 are presented in Table 8-20, Figure 8-16 and Figure 8-17. Capital costs have been estimated at 5 million (2012 AUD), while health benefits and net benefits have been estimated at 82 and -127 million (2012 AUD), respectively. Operating costs have been estimated at 205 million (2012 AUD).

Table 8-20: Replacement with Tier 2 $PM_{2.5}$ emissions, costs and benefits from 2012 to 2030

Metric	BAU-Actual certification	USEPA Tier 2-Minimum replacement year-ending-2017-Retrofit control efficiency (%)-0-NIL
$PM_{2.5}$ emissions (tonnes)	30,661	23,952
$PM_{2.5}$ reduction (tonnes)	0	6,709
Health cost - PV million (AUD)	507	425
Capital cost - PV million (AUD)	0	5
Operating cost - PV million (AUD)	0	205
Maintenance cost - PV million (AUD)	0	0
Health benefit - PV million (AUD)	0	82
Net benefit - NPV million (AUD)	0	-127#
#Negative net benefit means the sum of control, operating and maintenance costs are greater than the health benefits		

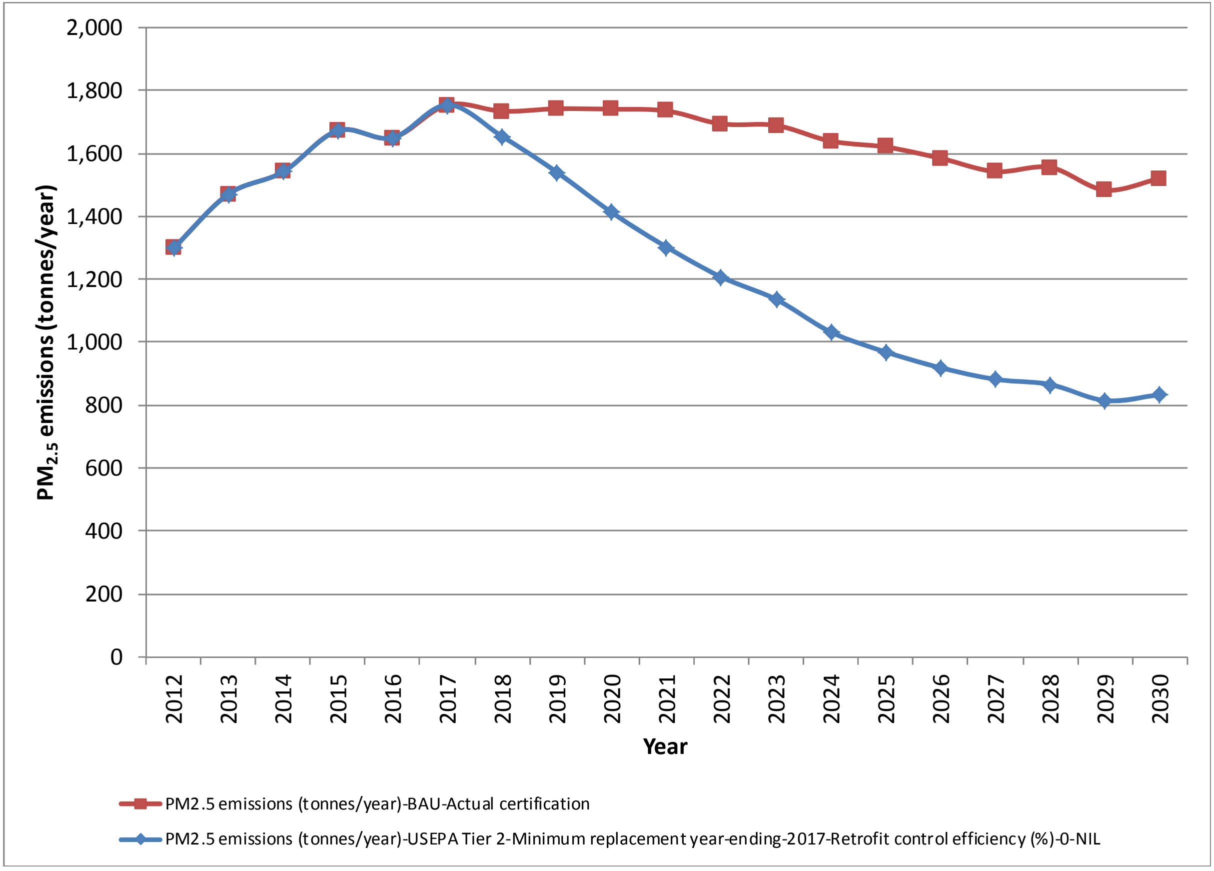

Figure 8-16: Replacement with Tier 2 $PM_{2.5}$ emissions from 2012 to 2030

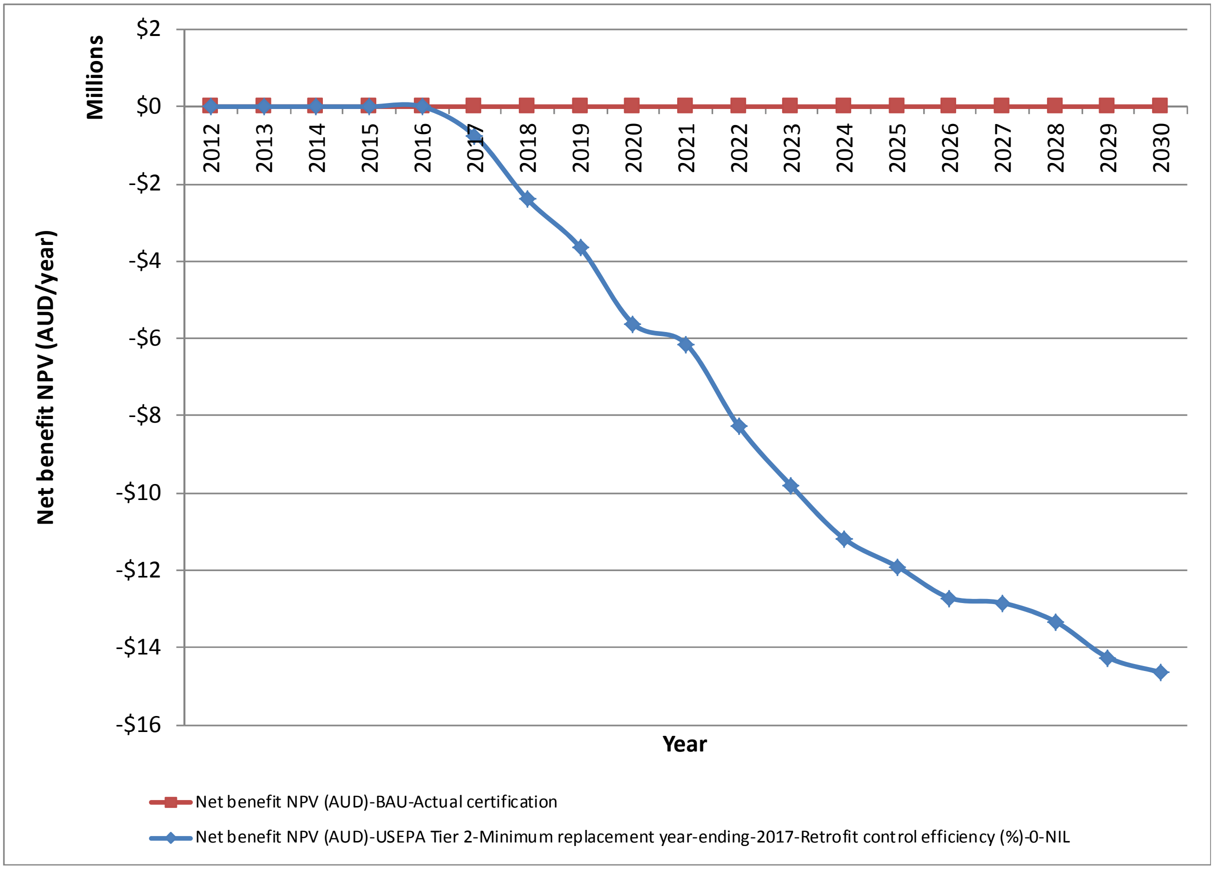

Figure 8-17: Replacement with Tier 2 net benefit from 2012 to 2030

8.3.8 Option 8 – Replacement with US Tier 3

Replacement with US Tier 3 $PM_{2.5}$ emissions, costs and benefits over the period from 2012 to 2030 are presented in Table 8-21, Figure 8-18 and Figure 8-19. Capital costs have been estimated at 22 million (2012 AUD), while health benefits and net benefits have been estimated at 79 and -85 million (2012 AUD), respectively. Operating costs have been estimated at 142 million (2012 AUD).

Table 8-21: Replacement with Tier 3 $PM_{2.5}$ emissions, costs and benefits from 2012 to 2030

Metric	BAU-Actual certification	USEPA Tier 3-Minimum replacement year-ending-2017-Retrofit control efficiency (%)-0-NIL
$PM_{2.5}$ emissions (tonnes)	30,661	24,157
$PM_{2.5}$ reduction (tonnes)	0	6,504
Health cost - PV million (AUD)	507	428
Capital cost - PV million (AUD)	0	22
Operating cost - PV million (AUD)	0	142
Maintenance cost - PV million (AUD)	0	0
Health benefit - PV million (AUD)	0	79
Net benefit - NPV million (AUD)	0	**-85#**
#Negative net benefit means the sum of control, operating and maintenance costs are greater than the health benefits		

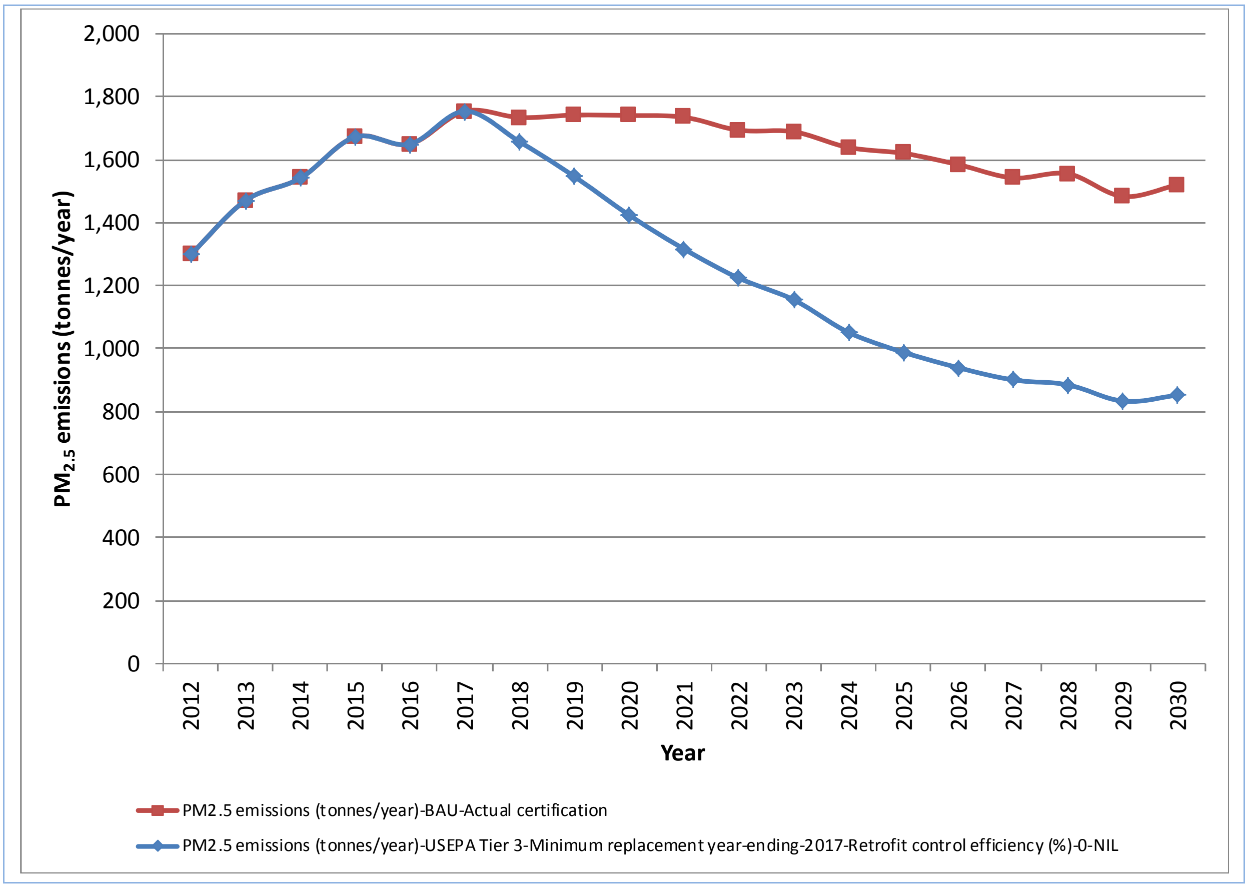

Figure 8-18: Replacement with Tier 3 $PM_{2.5}$ emissions from 2012 to 2030

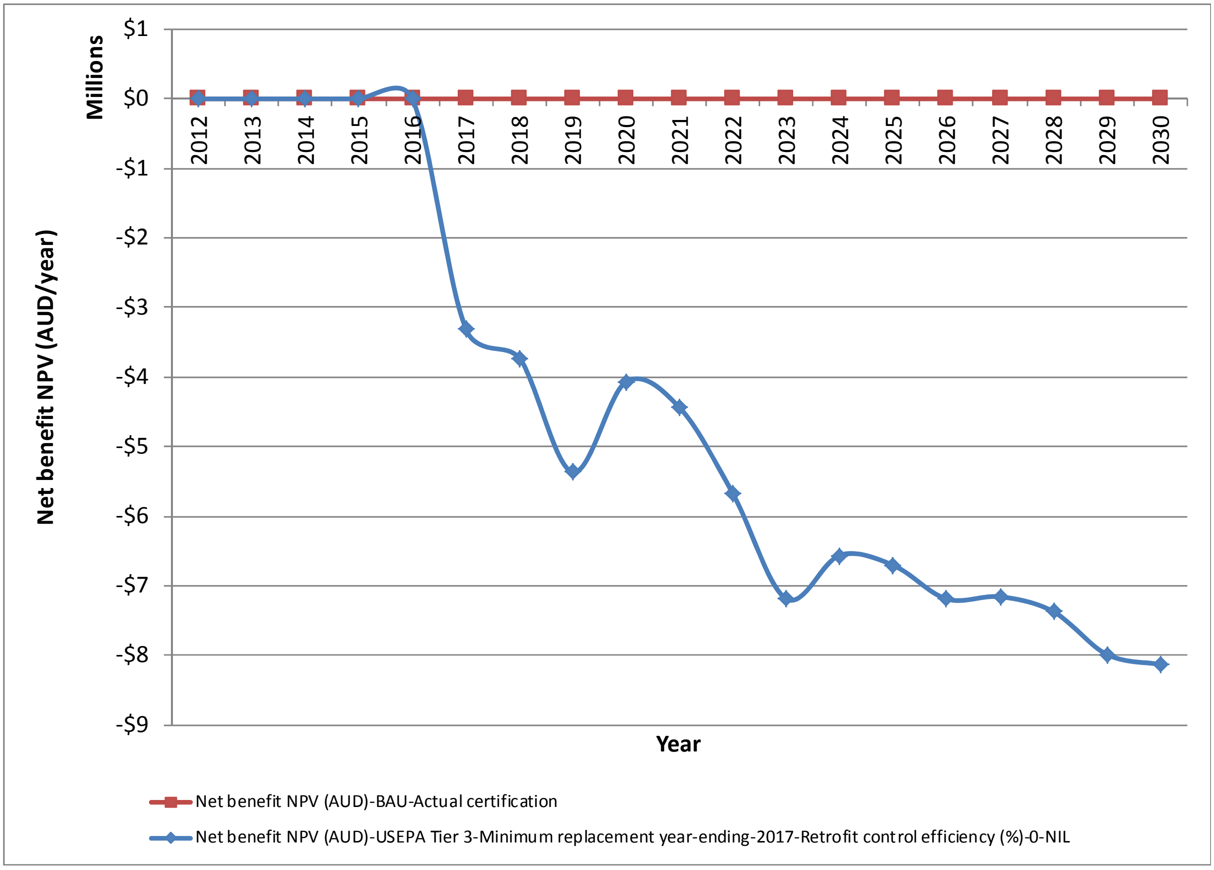

Figure 8-19: Replacement with Tier 3 net benefit from 2012 to 2030

8.3.9 Option 9 – Replacement with US Tier 4

Replacement with US Tier 4 $PM_{2.5}$ emissions, costs and benefits over the period from 2012 to 2030 are presented in Table 8-22, Figure 8-20 and Figure 8-21. Capital costs have been estimated at 107 million (2012 AUD), while health benefits and net benefits have been estimated at 162 and 273 million (2012 AUD), respectively. Operating costs and maintenance costs have been estimated at -256 and 39 million (2012 AUD), respectively. The operating costs savings achieved through improved fuel efficiency outweigh the capital costs and maintenance costs. This option has a net benefit, regardless of whether the health benefits are considered.

Table 8-22: Replacement with Tier 4 $PM_{2.5}$ emissions, costs and benefits from 2012 to 2030

Metric	BAU-Actual certification	USEPA Tier 4 final-Minimum replacement year-ending-2017-Retrofit control efficiency (%)-0-NIL
$PM_{2.5}$ emissions (tonnes)	30,661	18,180
$PM_{2.5}$ reduction (tonnes)	0	12,481
Health cost - PV million (AUD)	507	345
Capital cost - PV million (AUD)[1]	0	107
Operating cost - PV million (AUD)	0	**-256**[2]
Maintenance cost - PV million (AUD)	0	39
Health benefit - PV million (AUD)	0	162
Net benefit - NPV million (AUD)	0	273

[1] Does not include Adblue coal mine site infrastructure cost, which has been estimated to be $3.0 million
[2] Negative operating cost means savings achieved through improved fuel efficiency

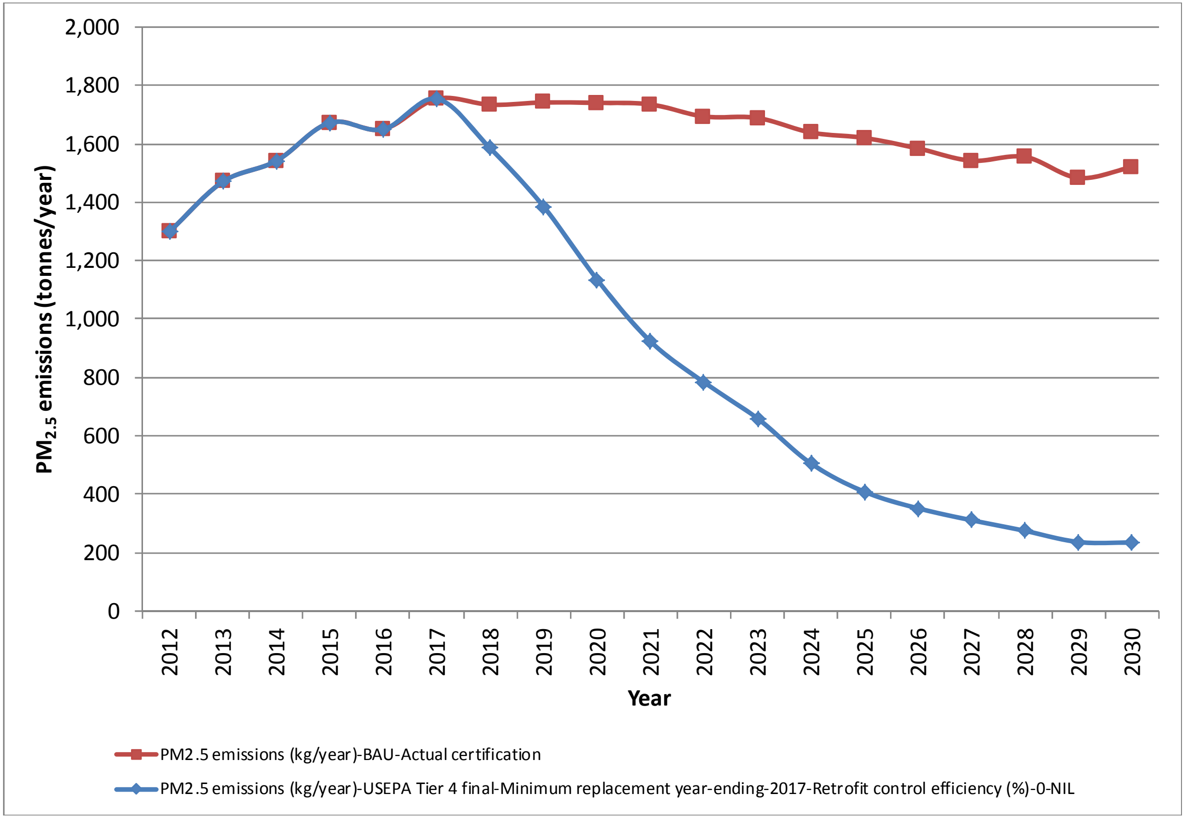

Figure 8-20: Replacement with Tier 4 $PM_{2.5}$ emissions from 2012 to 2030

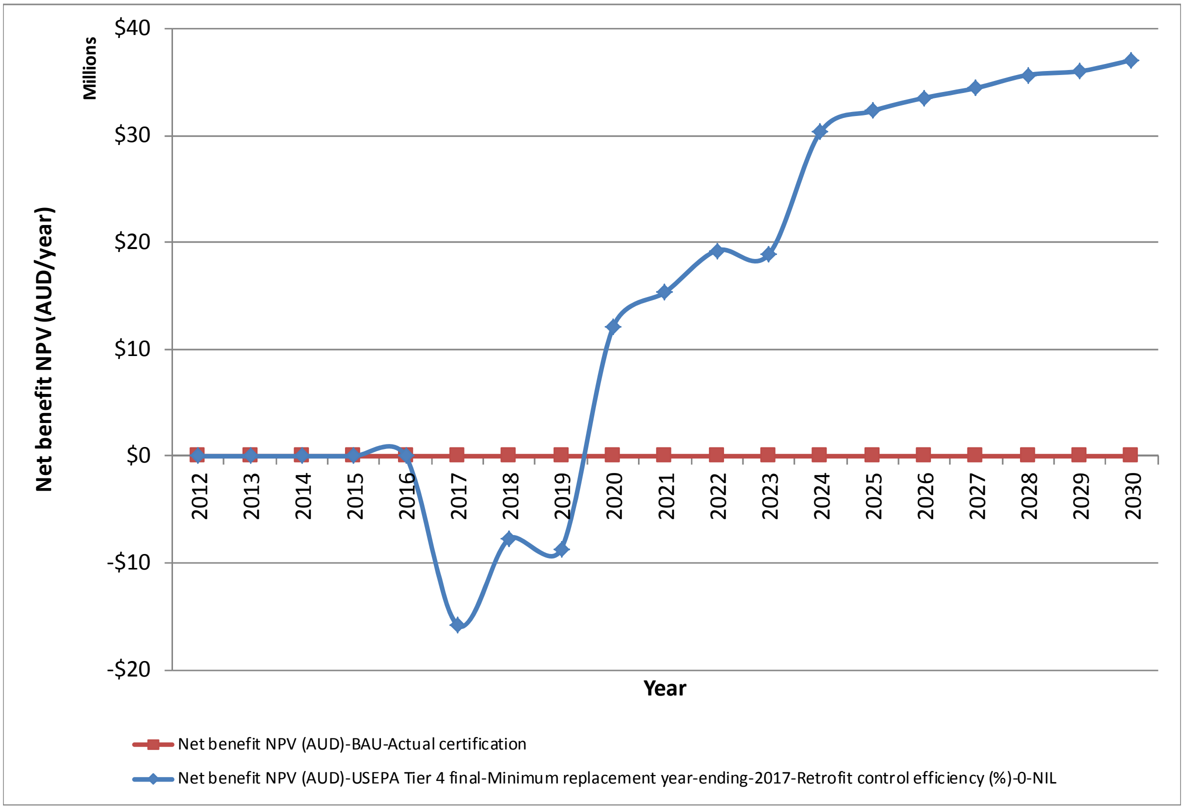

Figure 8-21: Replacement with Tier 4 net benefit from 2012 to 2030

8.3.10 Option 10 – Retrofit with passive DPF and replacement with US Tier 4

Retrofit with passive DPF combined with new replacement with US Tier 4 $PM_{2.5}$ emissions, costs and benefits over the period from 2012 to 2030 are presented in Table 8-23, Figure 8-22 and Figure 8-23. Capital costs have been estimated at 177 million (2012 AUD), while health benefits and net benefits have been estimated at 321 and 345 million (2012 AUD), respectively. Operating costs and maintenance costs have been estimated at -256 and 55 million (2012 AUD), respectively. This option clearly demonstrates that a combined retrofit and replacement strategy has the potential to yield the largest net benefits to communities situated near coal mines.

Table 8-23: Retrofit with passive DPF and replacement with Tier 4 $PM_{2.5}$ emissions, costs and benefits from 2012 to 2030

Metric	BAU-Actual certification	Actual certification-Minimum retrofit year-ending-2014-Retrofit control efficiency (%)-90-FDPF w/o actv. rgn.	USEPA Tier 4 final-Minimum replacement year-ending-2017-Retrofit control efficiency (%)-0-NIL	Retrofit plus Replacement
$PM_{2.5}$ emissions (tonnes)	30,661	8,977	18,180	9,472
$PM_{2.5}$ reduction (tonnes)	0	21,684	12,481	21,189
Health cost - PV million (AUD)	507	176	345	186
Capital cost - PV million (AUD)[1]	0	76	107	177
Operating cost - PV million (AUD)	0	0	**-256**[2]	**-256**[2]
Maintenance cost - PV million (AUD)	0	34	39	55
Health benefit - PV million (AUD)	0	331	162	321
Net benefit - NPV million (AUD)	0	220	273	345

[1] Does not include Adblue coal mine site infrastructure cost, which has been estimated to be $3.0 million
[2] Negative operating cost means savings achieved through improved fuel efficiency

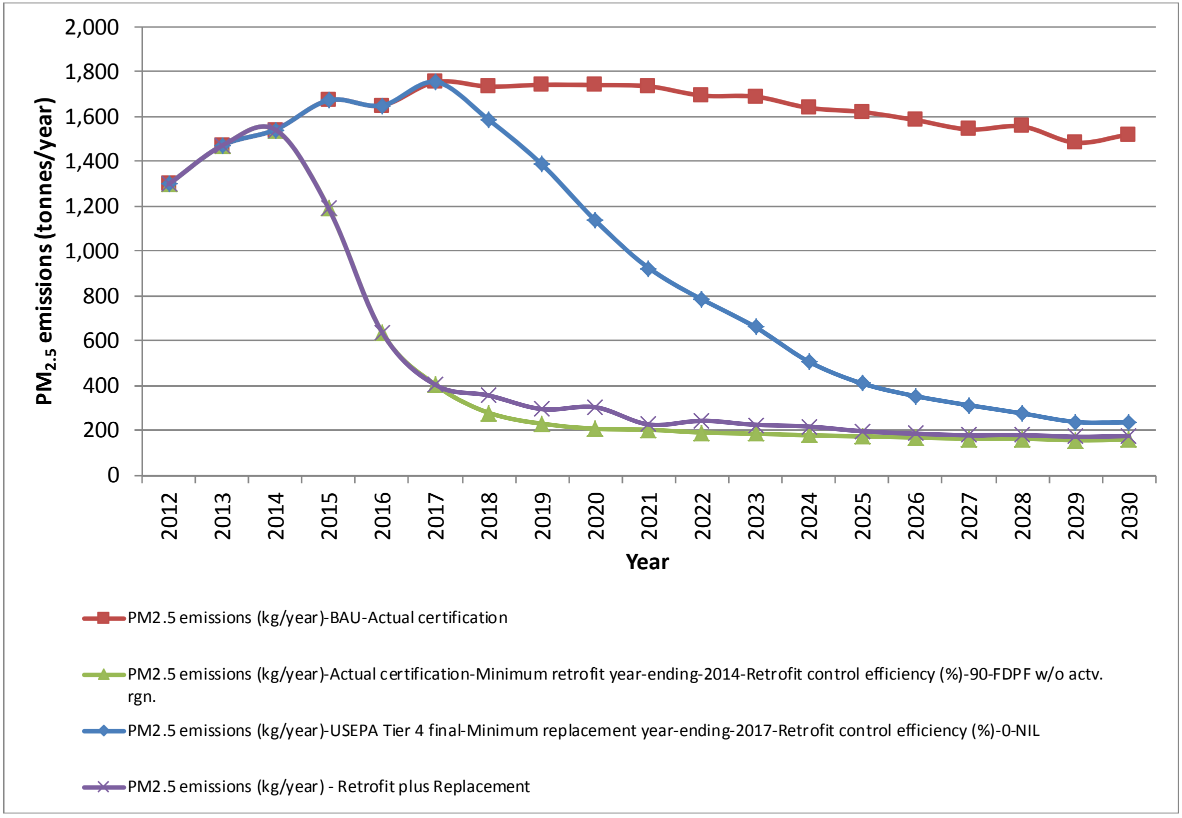

Figure 8-22: Retrofit with passive DPF and replacement with Tier 4 $PM_{2.5}$ emissions from 2012 to 2030

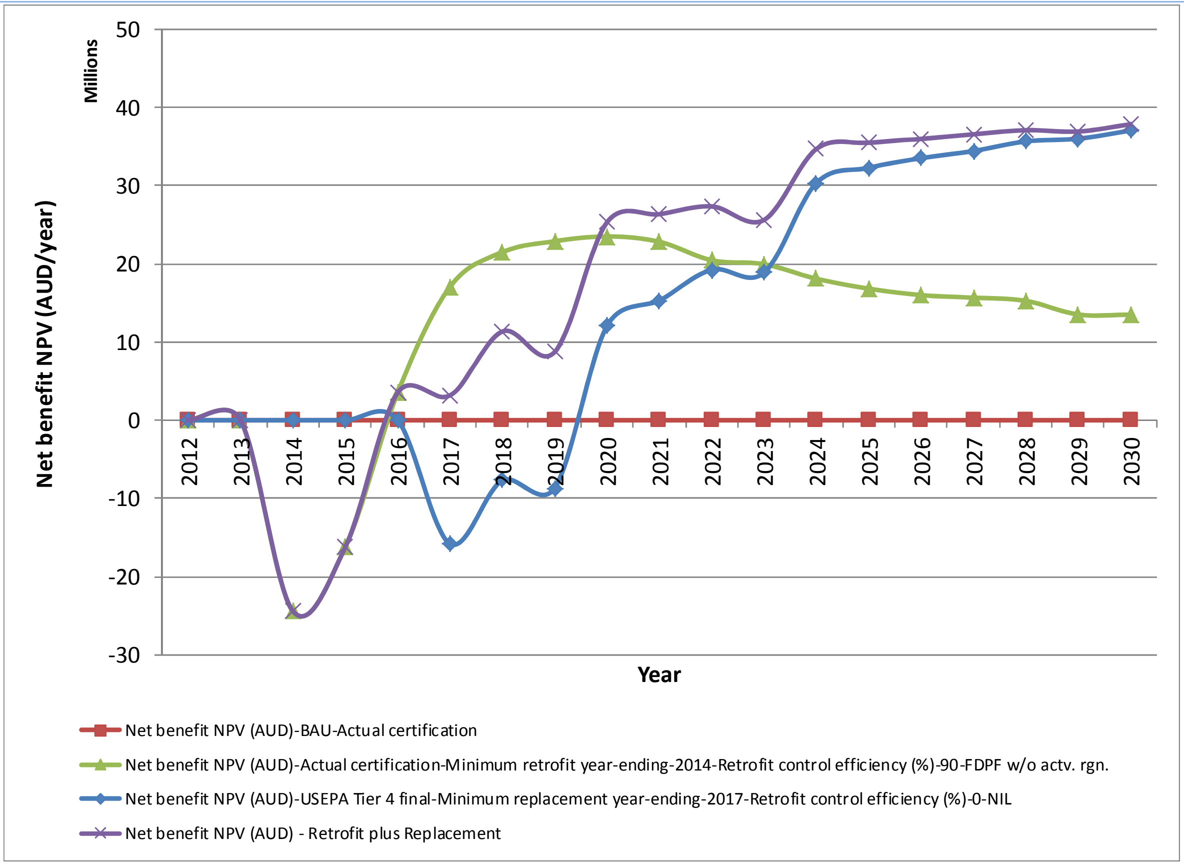

Figure 8-23: Retrofit with passive DPF and replacement with Tier 4 net benefit from 2012 to 2030

8.4 Summary of Cost Benefit Analysis

The CBA has evaluated a number of retrofit, replacement and combined retrofit and replacement options for reducing non-road diesel exhaust emissions and these are summarised in Table 8-24.

The CBA concludes that:

- all retrofit exhaust emission aftertreatment equipment options have net benefits ranging from 66 to 220 million (2012 AUD)
- replacing equipment with either US Tier 1 or Tier 4 emission standard compliant equipment have net benefits of 46 and 273 million (2012 AUD), respectively
- when replacing equipment with US Tier 4 emission standard compliant equipment, the operating costs savings due to improved fuel efficiency outweigh the capital costs and maintenance costs
- replacing equipment with US Tier 4 emission standard compliant equipment has a net benefit, regardless of whether the health benefits are considered
- combining in-service retrofit with passive DPF and replacing equipment with US Tier 4 emission standard compliant equipment has the highest net benefit of 345 million (2012 AUD)
- replacing equipment with either US Tier 2 or Tier 3 emission standard compliant equipment have negative net benefits due to lower fuel efficiency.

It should be noted the net benefits when replacing equipment with US Tier 4 emission standard compliant equipment do not include Adblue coal mine site infrastructure cost, which has been estimated to be $3.0 million (2012 AUD) (refer to Section 5.5.3 for further details).

Table 8-24: Summary of cost benefit analysis options

Option	Type	Description	2012 to 2030 $PM_{2.5}$ emissions (tonnes)		Present value (PV) million (2012 AUD)					
			Total	Reduction	Health cost	Capital cost	Operating cost	Maintenance cost	Health benefit	Net benefit
1	BAU	Nil	30,661	-	507	-	-	-	-	-
2	Retrofit	DOC	24,638	6,023	415	26	-	-	92	66
3	Retrofit	pDPF	21,024	9,637	360	54	-	-	147	93
4	Retrofit	passive DPF	8,977	21,684	176	76	-	34	331	220
5	Retrofit	active DPF	8,977	21,684	176	126	21	34	331	150
6	Replacement	Tier 1	26,541	4,120	461	-	-	-	46	46
7	Replacement	Tier 2	23,952	6,709	425	5	205	-	82	**-127#**
8	Replacement	Tier 3	24,157	6,504	428	22	142	-	79	**-85#**
9	Replacement	Tier 4	18,180	12,481	345	107^	**-256***	39	162	273
10	Retrofit & Replacement	passive DPF & Tier 4	9,472	21,189	186	177^	**-256***	55	321	345

^Does not include Adblue coal mine site infrastructure cost, which has been estimated to be $3.0 million

*Negative operating cost means savings achieved through improved fuel efficiency

#Negative net benefit means the sum of control, operating and maintenance costs are greater than the health benefits

8.5 Unquantified Costs & Benefits and Sensitivity Analysis

A number of factors could lead to either an under or over estimation of the net benefits presented in the CBA, including:

- **Forecast coal mine production** – the CBA forecasts emission reductions and net monetary benefits for existing EPA-licensed coal mines only. Since only the forecast saleable coal production for the 58 EPA-licensed coal mines that completed the survey has been considered (EPA, 2013b), future diesel consumption could have been underestimated by at least 40%, leading to increased $PM_{2.5}$ emissions and health costs. Saleable coal production and transport data is shown in Figure 8-24. The production data from 2012 to 2030 for existing EPA-licensed coal mines uses survey data for run-of-mine (ROM) coal (EPA, 2013b), which has been converted to saleable coal (Coal Services, 2003). The production data from 2012 to 2030 for proposed coal mines uses saleable coal forecasts (DRE, 2013). Transport data for 2014, 2019 and 2024 use ARTC saleable coal forecasts (ARTC, 2009). Since concurrent forecast coal production and transport data is available for three discrete years only, a comparison for 2024 is presented for illustrative purposes below:
  - For existing EPA-licensed coal mines alone, saleable coal production in 2024 has been estimated to be 197.6 Mt/year (EPA, 2013b), which is about 1.1 times saleable coal production at EPA-licensed coal mines in 2012 (176.9 Mt/year) (EPA, 2013b)
  - For existing EPA-licensed and proposed coal mines together, saleable coal production in 2024 has been estimated to be 310.3 Mt/year (EPA, 2013b & DRE, 2013), which is about 1.75 times saleable coal production at EPA-licensed coal mines in 2012 (176.9 Mt/year) (EPA, 2013b)
  - Forecast saleable coal transport in 2023 and 2024 have been estimated to be 276.7 (ARTC, 2014) and 278 Mt/year (ACIL, 2009) respectively, which are about 1.6 times saleable coal production at EPA-licensed coal mines in 2012 (176.9 Mt/year) (EPA, 2013b).

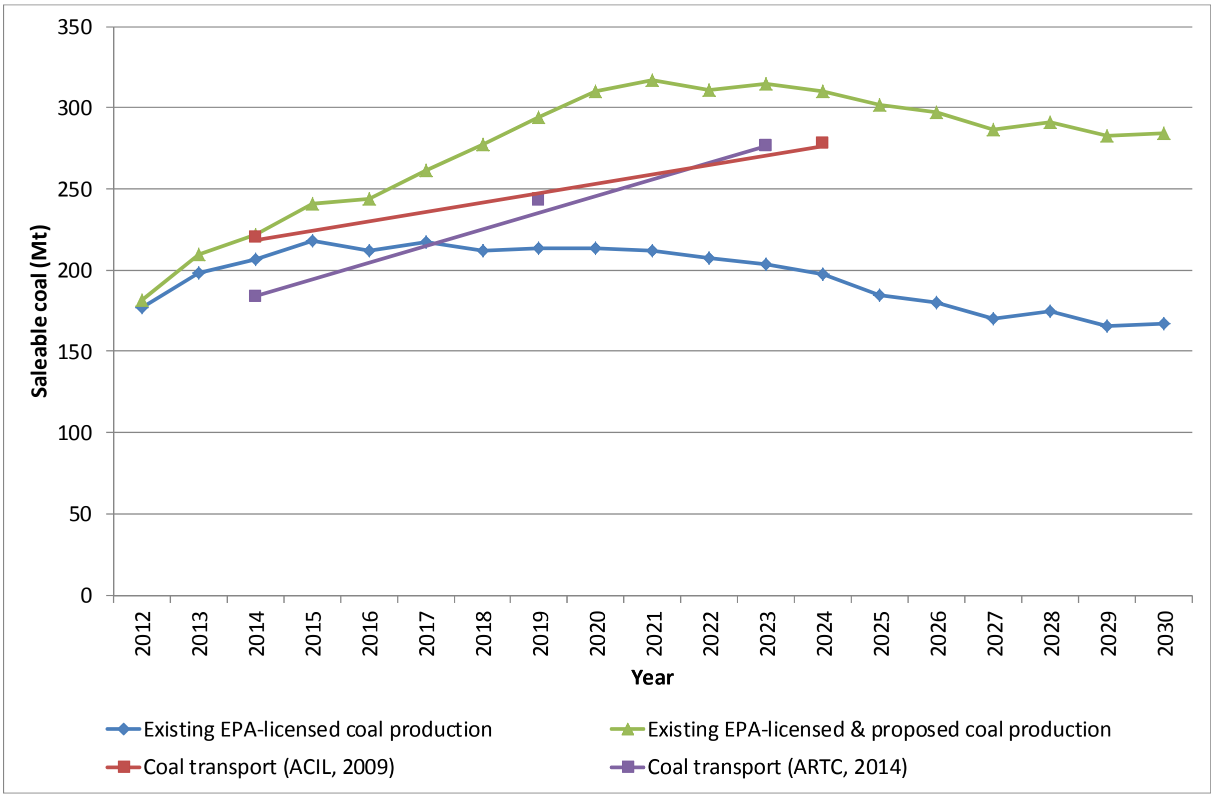

Figure 8-24: Forecast saleable coal production and transport

- **Assign a Significant Urban Area (SUA) to coal mine suburb/town** – the CBA assigns each coal mine suburb/town to the nearest Significant Urban Area (SUA) using a concordance table of Statistical Area 2 (SA2) to SUA, where SA2 is the finest geographical area for which Australian Bureau of Statistics (ABS) concordance tables are available on-line. The SA2 where each coal mine is located was firstly identified and the suburb/town then assigned to the corresponding SUA. In some cases, the physical location of the coal mine may lie outside the boundary of the SUA (which is less than 10 km in most instances), so a strict application of the damage costs approach would assign these to "Not in any SUA" with a unit damage cost for $PM_{2.5}$ of $370/tonne (2012 AUD). While the unit damage costs have been discretely calculated on a SUA basis, the airsheds approximated by each SUA are in reality part of a contiguous airshed with the surrounding areas. It should also be noted that $PM_{2.5}$ have atmospheric lifetimes of days to weeks and can travel from 100s to 1,000s of km. Since many of the Upper Hunter coal mines that are located outside of a SUA are within 10 km or less of the SUA boundary, the $PM_{2.5}$ emissions from those premises will still make a significant contribution to the ambient levels of $PM_{2.5}$ in that SUA.

  While it is not considered appropriate to use a $PM_{2.5}$ unit damage cost of $370/tonne (2012 AUD) corresponding to "Not in any SUA" for coal mines located within approximately 10 km of the SUA boundary, a sensitivity analysis has been done by assigning coal mines to the nearest SUA using a concordance table of suburb to SUA. When compared to the original SA2 to SUA assignment method, the business as usual (BAU) health costs for the 2012 base year decrease by 45% from $29.9M to $16.5M (2012 AUD). Similarly, the BAU health costs (2012 AUD) over the period from 2012 to 2030 decrease by 44% from $506.9M to $285.3M. The estimated net benefits using suburb to SUA are compared with the original SA2 to SUA assignment method for the various retrofit, replacement and combined retrofit and replacement options in Table 8-25. All retrofit (2 to 5), replacement (6 and 9) and combined retrofit and replacement (10) options still demonstrate a net benefit when using the alternative suburb to SUA assignment method.

Table 8-25: Net benefit sensitivity for suburb to SUA vs. SA2 to SUA assignment methods

Option	Type	Description	Net benefit (PV) million (2012 AUD)	
			SA2 → SUA	Suburb → SUA
1	BAU	Nil	-	-
2	Retrofit	DOC	66	26
3	Retrofit	pDPF	93	29
4	Retrofit	passive DPF	220	77
5	Retrofit	active DPF	150	7
6	Replacement	Tier 1	46	22
7	Replacement	Tier 2	**-127#**	**-163#**
8	Replacement	Tier 3	**-85#**	**-119#**
9	Replacement	Tier 4	273	209
10	Retrofit & Replacement	passive DPF & Tier 4	345	205

#Negative net benefit means the sum of control, operating and maintenance costs are greater than the health benefits

- **Health benefits beyond 2030** - the CBA forecasts emission reductions and net monetary benefits over the period from 2012 to 2030 only. Although additional emission reductions and net monetary benefits could potentially accrue by accounting for measures to reduce emissions from non-road diesels beyond 2030, they have not been quantified in the CBA but are likely to be substantial.

- **Health impacts of NO_x emissions** - the CBA forecasts emission reductions and net monetary benefits for primary $PM_{2.5}$ only. While retrofit options do not reduce NO_x emissions, replacement of equipment with ones that meet more stringent US non-road diesel regulations can achieve significant NO_x reductions (US Tier 4 can achieve up to 95% (<560 kW) and 60% (>560 kW) when compared to Tier 0). The *Reducing Emissions from Non-Road Diesel Engines Information Report* (EPA Information Report) estimates the NO_x unit damage costs to be about 2% (includes NO_2 and secondary PM) of $PM_{2.5}$ unit damage costs (EPA, 2014). The EPA Information Report uses UK Department of Environment, Food and Rural Affairs (DEFRA) NO_x unit damage costs *"For NO_x, the damage cost includes the health impacts of secondary particulate matter (as the emission of NO_x causes the formation of nitrates, which are classed as particulate matter). The damage cost does not, however, include the health impacts of ozone formation as a result of the emission of NO_x"* (DEFRA, 2013). While NO_x can contribute to human health impacts in three distinct ways, the CBA has not quantified the health costs for the following:
    - **Nitrogen dioxide** - NO_x mainly consists of nitric oxide (NO) and nitrogen dioxide (NO_2), which are collectively referred to as NO_x. Non-road diesels emit about 90–95% as NO and 5–10% as NO_2. Additional NO_2 is produced in ambient air when NO oxidises through atmospheric photochemical reactions. The reactive nature of NO_2 makes it a particular concern for human health. It can cause inflammation of the respiratory system and increase susceptibility to respiratory infection. Exposure to elevated concentrations of NO_2 has also been associated with increased mortality, particularly related to respiratory disease, and increased hospital admissions for asthma and heart disease patients (EPA, 2013c)
    - **Ozone** – ground-level ozone is an indicator of photochemical smog. Ozone is a secondary pollutant rather than a direct emission and is formed through atmospheric reactions between volatile organic compounds (VOC) and NO_x in the presence of sunlight
    - **Secondary PM** – NO_x and ammonia react in the atmosphere to form secondary nitrates, which contribute to PM pollution.

- **Workplace exposure** – the CBA quantifies health costs and benefits for the broader community only. Although emission reduction measures will also reduce occupational exposure to diesel exhaust, they have not been quantified in the CBA but are likely to be significant. "*Proven control technologies for reducing occupational exposure to diesel exhaust include: Low emission engines; Low emission fuel; Ventilation; Engine maintenance; Exhaust filtration systems; Air conditioned (filtered) operators' cabins; Operating practices; Driver and workforce education; and Personal protective equipment. Experience has shown that no one single simple solution exists and that individual operations need to explore which of the above control technologies best fit their circumstances"* (AIOH, 2013).

- **Fuel efficiency** – the CBA accounts for changes in fuel efficiency for both retrofit and replacement options. With the exception of active DPF, all other retrofit options do not significantly affect fuel efficiency. While replacement with either US Tier 2 or Tier 3 have negative net benefits, replacement with US Tier 4 has an estimated health benefit of 162 million (2012 AUD) and net benefit of 273 million (2012 AUD). Replacement with US Tier 4 has been estimated to deliver a net benefit of 110 million (2012 AUD) without including health benefits due to improved fuel efficiency. The fuel efficiency assumed in the CBA for US Tier 4 relative to Tier 0 for 560kW/>560kW engines is 98.5%/97.5%. If the US Tier 4 to Tier 0 relative fuel efficiency is varied to 99.6%/99.6% (for

560kW/>560kW engines), it results in the same estimated health benefit but with no net benefit, or in other words, the option breaks even. On the other hand, if the US Tier 4 to Tier 0 relative fuel efficiency is varied to 95%/95% (for 560kW/>560kW engines) according to the EPA Information Report (EPA, 2014), it results in the same estimated health benefit but with a net benefit of 599 million (2012 AUD).

- **Adblue consumption rate** - the CBA assumes a fleet average Adblue consumption of 1.4% expressed as a percentage of diesel consumption for US Tier 4 non-road diesels. Not all OEMs have made final announcements on the US Tier 4 NO_x control technology (either SCR or EGR) that will be used and the average percentage Adblue consumption may vary between manufacturers. A sensitivity analysis has been conducted for a fleet average Adblue consumption of 3.5% diesel consumption and this is compared with the CBA assumptions in Table 8-26. All replacement (9) and combined retrofit and replacement (10) options still demonstrate a net benefit when using the higher Adblue consumption rate.

Table 8-26: Sensitivity of cost benefit analysis options to Adblue consumption rate

Option	Type	Description	Net benefit (PV) million (2012 AUD)	
			1.4% Adblue	3.5% Adblue
9	Replacement	Tier 4	273	85
10	Retrofit & Replacement	passive DPF & Tier 4	345	158

- **Adblue storage tank and dispenser equipment** – the CBA does not include the cost of Adblue storage tank and dispenser equipment at coal mine sites. The total cost to equip all NSW open-cut coal mines with Adblue storage tanks and dispensers in order to cater for a fleet made up entirely of US Tier 4 non-road diesels has been estimated to be $3.0 million (2012 AUD), which is about 1% of the net benefit. All replacement (9) and combined retrofit and replacement (10) options still demonstrate a significant net benefit when including Adblue storage tank and dispenser equipment costs.

- **Exhaust aftertreatment retrofit capital, operating and maintenance costs** – the CBA uses cost data from exhaust aftertreatment equipment retrofit suppliers and OEMs (refer to Sections 6.4, 6.5, 6.6 and 8.2 for further details). A sensitivity analysis has been done using alternative costs for the retrofit of DOC and DPF exhaust aftertreatment equipment, including:
  - higher capital costs due to possibility of DPF exhaust back pressure exceeding manufacturer's specification when installed in conjunction with existing noise attenuation mufflers. (Refer to Section 6.1.3.7 for further details. Note that as DPFs typically provide around 25 dBa noise attenuation, existing mufflers may be removed or reduced in size with a consequent reduction in back pressure. Hence the sizing considered in the CBA is conservative)
  - higher installation costs than those provided by exhaust aftertreatment equipment retrofit suppliers
  - a small fuel consumption penalty due to a small increase in exhaust back pressure
  - higher cleaning costs/shorter cleaning interval.

Two exhaust aftertreatment equipment retrofit suppliers were contacted to provide new DPF sizes and costs for a clean exhaust back pressure of 2 kPa and a maximum operating exhaust back pressure of 5kPa with ash and soot loading; and separate estimates of the installation costs. The sensitivity analysis considers cost data as follows:

- DPF capital costs - $13,897 + 79.3 x Hp for 2 kPa clean and 5 kPa maximum operating exhaust back pressure
- DPF installation costs - $35,000 for large haul trucks > 1MW; $20,000 for haul trucks < 1MW, $25,000 for two engine excavators; and all other $15,000. DOC installation cost is 80% of DPF
- DPF operating cost - 0.30% fuel consumption penalty for passive DPFs assuming an average 3 kPa increase in operating exhaust pressure
- DPF maintenance cost - 0.50% of diesel cost
- DOC capital costs – unchanged.
- DOC installation costs – 80% of DPF installation costs.

The sensitivity analysis indicates that:

- DPF capital and installation costs – for DPF sized for 2 kPa clean exhaust back pressure with installation costs as above, the capital cost increases from $76 million to $238 million (2012 AUD) and the net benefit decreases from $220 million to $58 million (2012 AUD)
- DPF operating cost - for a 0.30% fuel consumption penalty using DPF, the operating cost increases from nothing to $62 million (2012 AUD) and the net benefit decreases from $220 million to $158 million (2012 AUD).
- DPF maintenance cost – for a DPF cleaning cost of 0.50% of diesel consumption, the maintenance cost increases from $34 million to $60 million (2012 AUD) and the net benefit decreases from $220 million to $195 million (2012 AUD)
- DOC capital and installation costs – for DOC installation costs detailed above, capital costs increase from $26 million to $55 million (2012 AUD) and the net benefit decreases from $66 million to $37 million (2012 AUD).

The results of the sensitivity analysis are compared with the CBA assumptions in Table 8-27. Note the DPF case where all costs are worst case is unlikely, since the significantly larger DPF sized to give the low back pressure would decrease rather than increase DPF cleaning intervals. The 2 kPa back pressure sizing is also considered quite conservative as DPFs typically provide around 25 dBa exhaust noise attenuation. Existing mufflers may be removed or reduced in size with consequent reduction in exhaust back pressure, to allow a DPF sized with a clean exhaust back pressure higher than 2 kPa.

Table 8-27: Net benefit sensitivity to aftertreatment cost parameters

Case	Net benefit (PV) million (2012 AUD)			
	Capital cost	Operating cost	Maintenance cost	Net benefit
DPF sensitivity analysis				
CBA base case	76	0	34	220
2 kPa clean exhaust back pressure & high installation costs	238	0	34	58
0.30% fuel consumption penalty	76	62	34	158
Cleaning cost of 0.50% of diesel consumption	76	0	60	195
2 kPa clean exhaust back pressure, high installation, 0.3% fuel consumption penalty & Cleaning cost of 0.50% of diesel consumption	238	62	60	-29

Case	Net benefit (PV) million (2012 AUD)			
	Capital cost	Operating cost	Maintenance cost	Net benefit
DOC sensitivity analysis				
CBA base case	26	0	0	66
High installation costs	55	0	0	37

- **Exhaust aftertreatment weight and space constraints** – the CBA does not include the impact of DPF retrofit on payload and any associated loss in productivity. It is acknowledged that certain equipment may have engineering limitations and these may not be suitable for DPF retrofit. Diesel particulate filter retrofits for very large open-cut coal mining equipment have considerable weight and size. For example, a 2 kPa back pressure DPF installation on a 2,700 kW haul truck is estimated to weigh about 7.5 tonnes (2% of the haul truck payload) with a volume of 16 m^3. The physical size of the DPF is not likely to result in any change in operating cost but may impact on the feasibility of retrofitting certain pieces of mining equipment. Weight and space constraints associated with retrofitting exhaust aftertreatment equipment should be addressed for each piece of mining equipment used by EPA-licensed coal mines in the PRP process.

  Since DOC are significantly smaller and lighter than DPF and can generally be accommodated within existing exhaust systems and mufflers, DOC retrofit is unlikely to impact on payload and have any associated loss in productivity.

- **Discount rate** - the CBA assumes a discount rate of 7%, which is based on NSW Treasury economic appraisal guidance (NSW Treasury, 2007a, 2007b & 2007c). A sensitivity analysis has been done assuming discount rates of 4% and 10% based on the following guidance *"While there may be no universally accepted 'correct' discount rate, interpretation of appraisal results will be impossible if different agencies use different discount rates. The solution is the application of a standard set of real discount rates of 4%, 7% and 10% to see if the outcome is sensitive to such variations and, if it is, to make the critical 'break-even' rate clear in the analysis results. The central real discount rate is therefore 7% with sensitivity tests on the use of 4% and 10%"* (NSW Treasury, 2007b). The sensitivity analysis concludes that retrofit (2 to 5), replacement (6 & 9) and combined retrofit and replacement (10) options have net benefits for discount rates ranging from 4% to 10%. On the other hand, replacement (7 & 8) options have negative net benefits for discount rates ranging from 4% to 10%. The CBA sensitivity analysis results for the various retrofit, replacement and combined retrofit and replacement options are summarised in Table 8-28.

Table 8-28: Sensitivity of cost benefit analysis options to discount rate

Option	Type	Description	Net benefit (PV) million (2012 AUD)		
			4%	7%	10%
1	BAU	Nil	-	-	-
2	Retrofit	DOC	94	66	46
3	Retrofit	pDPF	137	93	63
4	Retrofit	passive DPF	313	220	156
5	Retrofit	active DPF	238	150	91
6	Replacement	Tier 1	67	46	32

Option	Type	Description	Net benefit (PV) million (2012 AUD)		
			4%	7%	10%
7	Replacement	Tier 2	-92#	-127#	-151#
8	Replacement	Tier 3	-55#	-85#	-104#
9	Replacement	Tier 4	315	273	247
10	Retrofit & Replacement	passive DPF & Tier 4	415	345	300
#Negative net benefit means the sum of control, operating and maintenance costs are greater than the health benefits					

- **Voluntary equipment replacement strategy** - the CBA assumes the voluntary equipment replacement strategy for the BAU or 'do nothing' option is to purchase equipment with the same level of emissions certification as existing equipment. In order to benchmark the existing performance of NSW coal mines, $PM_{2.5}$ emissions have been estimated for non-road diesels in 2012 at the 58 EPA-licensed coal mines that completed the EPA survey (EPA, 2013b) by assuming the fleet is composed of equipment that is exclusively either US Tier 0, Tier 1, Tier 2, Tier 3 or Tier 4. The annual BAU $PM_{2.5}$ emissions from non-road diesels at NSW coal mines in 2012 have been compared with US Tier 0 to Tier 4 emissions and these are shown in Figure 8-25.

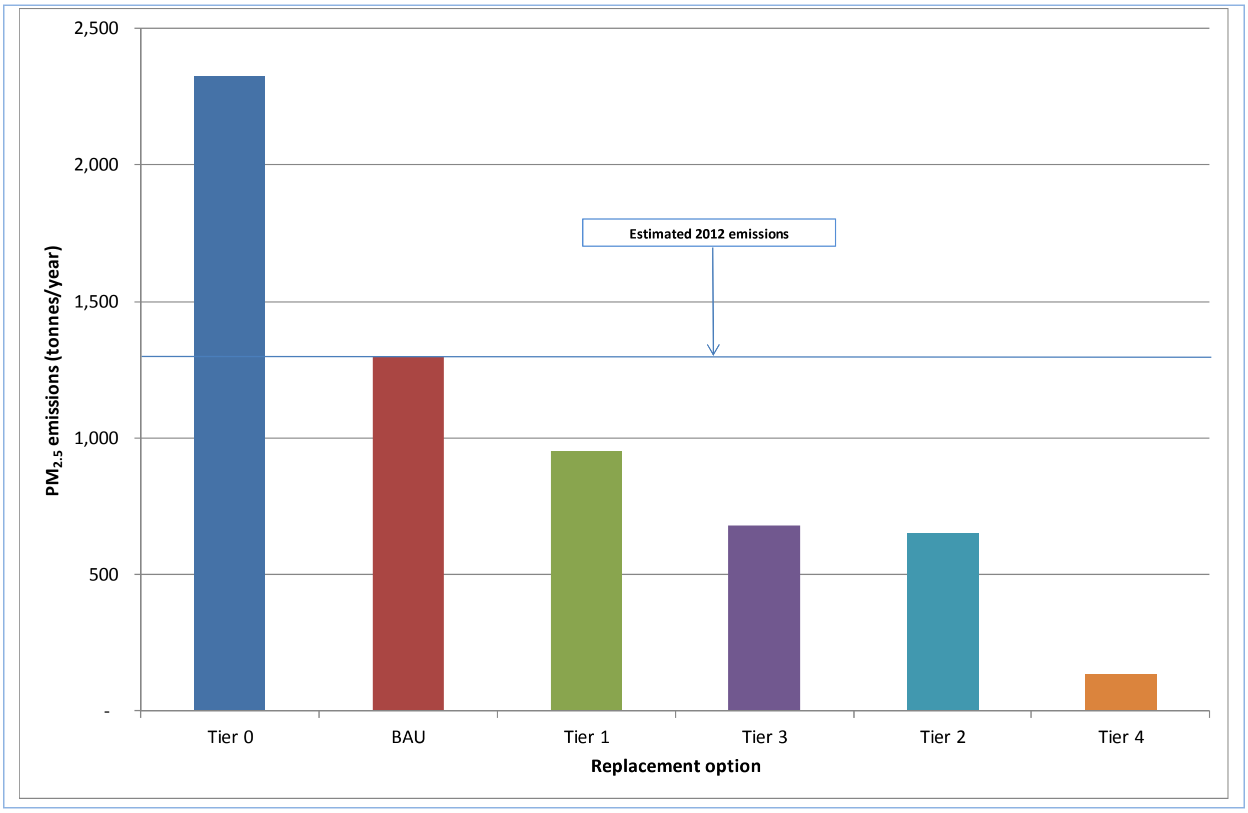

Figure 8-25: Business as usual vs. US Tier 0 to Tier 4 $PM_{2.5}$ emissions for surface equipment at EPA-licensed coal mines in 2012

It is quite clear the existing BAU $PM_{2.5}$ emissions are approximately 55%, 135% and 200% of a fleet made up entirely of US Tier 0, Tier 1 and Tier 2 compliant non-road diesels, respectively and the actual current fleet performance lies somewhere between US Tier 0 and Tier 1. As a worst case in order to maximise costs (especially fuel consumption) and minimise benefits (reduction in $PM_{2.5}$ emissions), a sensitivity analysis has been done by assuming the existing fleet performance is either

US Tier 1 or Tier 2. In other words, the voluntary equipment replacement strategy for the BAU option is to purchase equipment with either US Tier 1 or Tier 2 level of emissions certification. Assuming the existing fleet performance is either US Tier 1 or Tier 2 provides a suitable basis for evaluating the likely range of net benefits associated with a mandated US Tier 4 replacement strategy. This approach results in a voluntary equipment replacement strategy that has between 75% (US Tier 1) and 50% (US Tier 2) of the $PM_{2.5}$ emissions when compared to BAU.

The voluntary equipment replacement strategy sensitivity analysis concludes that:

- if the existing fleet performance is US Tier 2, retrofit (2 to 4), replacement (9) and combined retrofit and replacement (10) options have net benefits. On the other hand, one retrofit (5) option has a negative net benefit of -6 million (2012 AUD)
- if the existing fleet performance is US Tier 1, retrofit (2 to 5), replacement (9) and combined retrofit and replacement (10) options have net benefits
- as the natural turnover of the existing fleet tends to either US Tier 2 and/or Tier 3 emission standards compliant equipment, the net benefits associated with a mandated US Tier 4 replacement strategy increase due to improved fuel efficiency.

The sensitivity analysis results for the various retrofit, replacement and combined retrofit and replacement options are summarised in Table 8-29.

Table 8-29: Sensitivity to voluntary equipment replacement strategy

Option	Type	Description	Net benefit (PV) million (2012 AUD)		
			Actual certification	Tier 1	Tier 2
2	Retrofit	DOC	66	45	23
3	Retrofit	pDPF	93	59	24
4	Retrofit	passive DPF	220	145	64
5	Retrofit	active DPF	150	76	**-6#**
9	Replacement	Tier 4	273	124	584
10	Retrofit & Replacement	passive DPF & Tier 4	345	217	391
#Negative net benefit means the sum of control, operating and maintenance costs are greater than the health benefits					

- **Administration and compliance costs** - the CBA does not include administration and compliance costs. The key costs associated with a non-road diesel retrofit and/or replacement program include the following:
  - retrofit - exhaust aftertreatment equipment and installation costs.
  - replacement – incremental engine capital costs
  - administration costs to implement, monitor and review the new requirements.
  - industry compliance costs.
  - operating, maintenance and fuel consumption costs.

The EPA Information Report (EPA, 2014) presents the costs and benefits associated with introducing US Tier 4 final / EU Stage III A/Stage IV emission standards in 2018 for non-road diesels greater than 19 kW over a 41 year period. Administration and compliance costs have been estimated to account for 0.5% of total costs over the entire 41 year period, or 1% of total costs over the 19 year period considered in this CBA.

8.6 Compliance Monitoring

The *Protection of the Environment Operations Act 1997* (POEO Act) (PCO, 2010) provides the statutory framework for managing air emissions in NSW.

Air pollution related Sections 124 and 125 of the POEO Act require that operation of plant and maintenance work on plant is done in a proper and efficient manner. Section 128 of the POEO Act requires that activities are carried out using those practicable means that may be required to prevent or minimise air pollution.

Part 5.4 (Air pollution), Division 1 General of the POEO Act specifically states:

124 Operation of plant (other than domestic plant)
The occupier of any premises who operates any plant in or on those premises in such a manner as to cause air pollution from those premises is guilty of an offence if the air pollution so caused, or any part of the air pollution so caused, is caused by the occupier's failure:
(a) to maintain the plant in an efficient condition, or
(b) to operate the plant in a proper and efficient manner.

125 Maintenance work on plant (other than domestic plant)
The occupier of any premises who carries out maintenance work on any plant in or on those premises in such a manner as to cause air pollution from those premises is guilty of an offence if the air pollution so caused, or any part of the air pollution so caused, is caused by the occupier's failure to carry out that work in a proper and efficient manner.

128 Standards of air impurities not to be exceeded
Where neither such a standard nor rate has been so prescribed, the occupier of any premises must carry on any activity, or operate any plant, in or on the premises by such practicable means as may be necessary to prevent or minimise air pollution.

Best management practice (BMP) is clearly the guiding principle in meeting the Air pollution requirements of the POEO Act.

- **For in-service non-road diesel retrofit** - the performance of retrofit exhaust aftertreatment equipment should be certified by an independent body acceptable to the EPA, for example, either the European Verification of Emission Reduction Technologies (VERT) scheme (VERT, 2014), USEPA (USEPA, 2014), California Air Resources Board (CARB, 2014) or by an acceptable internationally recognised independent emission certification laboratory. The equipment should be supported by manufacturer's performance guarantees, consumer warranties and instructions for proper and efficient operation and maintenance.

- **For new replacement non-road diesels** – for equipment that are certified as US Tier 4, all USEPA requirements related to labelling, warranties and maintenance etc. should also apply in the proposed NSW framework (USEPA, 2013a). This would minimise costs to OEMs and consumers by ensuring non-road diesels in NSW conform to overseas requirements by harmonising with US and EU non-road diesel emission standards.

EPA-licensed coal mines are required to submit an annual return form to the EPA. The annual return is a statement of compliance with environment protection licence (EPL) conditions for the preceding 12 months. The non-road diesel performance standards, operation and maintenance requirements for in-service retrofit and new replacement equipment should be included as EPL conditions and compliance determined using the existing annual return process.

9 SUMMARY AND RECOMMENDATIONS

The *Protection of the Environment Operations Act 1997* (POEO Act) (PCO, 2010) provides the statutory framework for managing air emissions in NSW. Reducing risks to human health through pollution prevention, cleaner production, reduction of pollution to harmless levels, application of the waste management hierarchy (i.e. reduction, re-use, recovery and recycling), continual environmental improvement and environmental monitoring are the broad objectives of the POEO Act (Chapter 1, Section 3). Air pollution related Sections 124 to 126 of the POEO Act require that operation of plant, maintenance work on plant and dealing with materials is done in a proper and efficient manner. Section 128 of the POEO Act requires that activities are carried out using those practicable means that may be required to prevent or minimise air pollution. Best management practice (BMP) is clearly the guiding principle in meeting the Objects and Air pollution requirements of the POEO Act.

While the EPA has powers to include environment protection licence (EPL) conditions aimed at preventing or minimising air pollution emissions from non-road diesels at coal mines, EPLs presently include generic requirements (EPA, 2013a), which are essentially a reiteration of Part 5.4 (Air pollution), Division 1 General of the POEO Act. While BMP is the guiding principle of these operating conditions, the EPLs haven't traditionally included prescriptive requirements. However, the approach has now evolved through the *Dust Stop* program (EPA, 2011).

The *Dust Stop* program aims to ensure that the most reasonable and feasible PM control options are implemented by each coal mine. The *Dust Stop* program is being implemented through pollution reduction programs (PRP) attached to each coal mine EPL, which aim to reduce emissions of wheel generated dust and dust from handling overburden. The PRP typically include: Key performance indicator; Monitoring method; Location, frequency and duration of monitoring; Record keeping; and Compliance reporting. The *Dust Stop* program provides a sound model for reducing non-road diesel exhaust emissions at EPA-licensed coal mines in NSW.

Given that approximately 90% of all diesel consumed by EPA-licensed coal mines is in the high power (≥ 560 kW) equipment class (EPA, 2013b), this project is principally aimed at evaluating options for reducing PM emissions from non-road diesels in this class.

Since occupational exposure to non-road diesel exhaust emissions at underground coal mines is regulated by the Division of Resources and Energy (DRE) under the *Coal Mine Health and Safety Act 2002* (CMHS Act) (PCO, 2013b), non-road diesels used in underground applications are not within the scope of this project. At EPA-licensed coal mines, over 99% of diesel is consumed by non-road diesels in surface applications, while less than 1% is consumed in underground applications (EPA, 2013b). Since the majority of diesel is consumed in surface applications, a program aimed at reducing non-road diesel exhaust emissions from these equipment will achieve the greatest health benefit to communities situated near coal mines.

Regulated emission limits for non-road diesels have been in force in the United States (US) (USEPA, 2013a) and European Union (EU) (European Commission, 2013) since the mid-to-late 1990s, and were more recently introduced in Canada, Russia, Switzerland, Turkey, Japan, China, India, South Korea, Singapore and Brazil (Ecopoint Inc., 2013a). With the exception of non-road diesels used in underground coal mine applications, there are no regulations which specifically apply to emissions from non-road diesels in Australia or NSW. A study to gather information and scope possible actions for non-road diesels in Australia found that significant health benefits ranging from $2.5 to $4.7 billion by 2030 could potentially be achieved by reducing PM_{10} and NO_x emissions (Environ, 2010).

Retrofit exhaust emission control equipment are a mature technology and able to achieve between 25% (diesel oxidation catalysts (DOC)) (DieselNet, 2012 & Joshi et. al., 2011) and 90% (diesel particulate filters (DPF)) (Lanni et. al., 2001; Chatterjee et. al., 2001; Joshi et. al., 2011 & DieselNet, 2011b) reduction in PM, depending on the technology selected.

A survey of EPA-licensed coal mines (EPA, 2013b) was carried out to provide the detailed supporting technical data required to complete a cost benefit analysis (CBA) and objectively establish whether there are technically and economically feasible options available to reduce non-road diesel emissions.

The NSW Minerals Council coordinated industry consultation with BHP Billiton, Peabody, Rio Tinto and Xstrata on the draft EPA survey during February and March 2013. The draft EPA survey was modified in line with comments received during industry consultation.

The EPA survey was issued to 64 EPA-licensed coal mines on 11 April 2013 under the Protection of the Environment Operations Act 1997 (POEO Act) (PCO, 2010) using a Section 191 Notice to Provide Information and/or Records and ended on 24 May 2013.

A 100% response rate to the survey was achieved with high quality data completed and submitted by the 58 operating EPA-licensed coal mines in NSW. The EPA granted six exemptions from participating in the survey, considering these coal mines have little or no non-road diesels activity because they are either closed with rehabilitation complete or in care and maintenance with no foreseeable plans to commence production.

A CBA has evaluated a number of options for reducing exhaust PM emissions from non-road diesels at NSW coal mines over the period from 2012 to 2030, including:

- retrofitting in-service equipment with PM exhaust aftertreatment technologies
- procuring replacement equipment that is compliant with EU (European Commission, 2013) and/or US (USEPA, 2013a) emission standards, and/or
- adopting ultra-low sulfur diesel (10 ppm sulfur) (Attorney-General's Department, 2009a), for all 64 coal mines in NSW that hold a current environment protection licence (EPL) (EPA, 2013a).

Over 99% of diesel consumed by EPA-licensed coal mines has a sulfur content of ≤ 10 ppm and complies with the *Fuel Standard (Automotive Diesel) Determination 2001* (Attorney-General's Department, 2009a), while less than 1% of diesel consumed (predominantly in underground applications) has a sulfur content of 50 – 500 ppm (EPA, 2013b). Given the high uptake of ultra-low sulfur diesel, there is no technical impediment to retrofit in-service non-road diesels with advanced exhaust emission control equipment (DPF) and/or replace with new equipment that has US Tier 4 emissions certification at NSW coal mines.

Australian ultra-low sulfur diesel is technically compatible with advanced exhaust aftertreatment and US Tier 4 technologies, so there are no fuel quality related barriers associated with adopting these low diesel emission control technologies at NSW coal mines.

The CBA concludes that:

- all retrofit exhaust emission aftertreatment equipment options have net benefits ranging from 66 to 220 million (2012 AUD)
- replacing equipment with either US Tier 1 or Tier 4 emission standard compliant equipment have net benefits of 46 and 273 million (2012 AUD), respectively
- when replacing equipment with US Tier 4 emission standard compliant equipment, the operating costs savings due to improved fuel efficiency outweigh the capital costs and maintenance costs

- replacing equipment with US Tier 4 emission standard compliant equipment has a net benefit, regardless of whether the health benefits are considered
- combining in-service retrofit with passive DPF and replacing equipment with US Tier 4 emission standard compliant equipment has the highest net benefit of 345 million (2012 AUD)
- replacing equipment with either US Tier 2 or Tier 3 emission standard compliant equipment have negative net benefits due to lower fuel efficiency.

It should be noted the net benefits when replacing equipment with US Tier 4 emission standard compliant equipment do not include Adblue coal mine site infrastructure cost, which has been estimated to be $3.0 million (2012 AUD) (refer to Section 5.5.3 for further details).

A number of factors could lead to either an under or over estimation of the net benefits presented in the CBA, including:

- **Forecast coal mine production** – the CBA forecasts emission reductions and net monetary benefits for existing EPA-licensed coal mines only. Since only the forecast saleable coal production for the 58 EPA-licensed coal mines that completed the survey has been considered (EPA, 2013b), future diesel consumption could have been underestimated by at least 40%, leading to increased $PM_{2.5}$ emissions and health costs
- **Assign a Significant Urban Area (SUA) to coal mine suburb/town** - the CBA assigns each coal mine suburb/town to the nearest Significant Urban Area (SUA) using a concordance table of Statistical Area 2 (SA2) to SUA. While the unit damage costs have been discretely calculated on a SUA basis, the airsheds approximated by each SUA are in reality part of a contiguous airshed with the surrounding areas. It should also be noted that $PM_{2.5}$ have atmospheric lifetimes of days to weeks and can travel from 100s to 1,000s of km. Since many of the Upper Hunter coal mines that are located outside of a SUA are within 10 km or less of the SUA boundary, the $PM_{2.5}$ emissions from those premises will still make a significant contribution to the ambient levels of $PM_{2.5}$ in that SUA. A sensitivity analysis has been done by assigning coal mines to the nearest SUA using a concordance table of suburb to SUA. The sensitivity analysis concludes that all retrofit, replacement and combined retrofit and replacement options with the exception of two have net benefits for any SUA assignment method. Replacement with either US Tier 2 or Tier 3 emission standards compliant equipment have negative net benefits for any SUA assignment method
- **Health benefits beyond 2030** - the CBA forecasts emission reductions and net monetary benefits over the period from 2012 to 2030 only. Although additional emission reductions and net monetary benefits could potentially accrue by accounting for measures to reduce emissions from non-road diesels beyond 2030, they have not been quantified in the CBA but are likely to be substantial
- **Health impacts of NO_x emissions** - the CBA forecasts emission reductions and net monetary benefits for primary $PM_{2.5}$ only. While retrofit options do not reduce NO_x emissions, replacement of equipment with ones that meet more stringent US non-road diesel regulations can achieve significant NO_x reductions. The NSW Environment Protection Authority (EPA) *Reducing Emissions from Non-Road Diesel Engines Information Report* (EPA Information Report) estimates the NO_x unit damage costs to be about 2% (includes NO_2 and secondary PM) of $PM_{2.5}$ unit damage costs (EPA, 2014). While NO_x can contribute to human health impacts in three distinct ways, the CBA has not quantified the health costs and benefits associated with NO_2, O_3 and secondary PM
- **Workplace exposure** – the CBA quantifies health costs and benefits for the broader community only. Although emission reduction measures will also reduce occupational exposure to diesel exhaust, they have not been quantified in the CBA but are likely to be significant (AIOH, 2013)
- **Fuel efficiency** – the CBA accounts for changes in fuel efficiency for both retrofit and replacement options. With the exception of active DPF, retrofit options do not significantly affect fuel efficiency. While replacement with either US Tier 2 or Tier 3 options have negative net benefits, replacement with US Tier 4 has a net benefit regardless of whether the health benefits are considered due to

improved fuel efficiency. If the US Tier 4 fuel efficiency is varied within a reasonable range, the net benefits of the option range from break even to 599 million (2012 AUD)

- **Adblue consumption rate** - the CBA assumes a fleet average Adblue consumption of 1.4% expressed as a percentage of diesel consumption for US Tier 4 non-road diesels. Not all OEMs have made final announcements on the US Tier 4 NO_x control technology (either SCR or EGR) that will be used and the average percentage Adblue consumption may vary between manufacturers. A sensitivity analysis has been conducted for a fleet average Adblue consumption of 3.5% diesel consumption. The sensitivity analysis concludes that all replacement and combined retrofit and replacement options that include US Tier 4 demonstrate a significant net benefit when using the higher Adblue consumption rate
- **Adblue storage tank and dispenser equipment** – the CBA does not include the cost of Adblue storage tank and dispenser equipment at coal mine sites. The total cost to equip all NSW open-cut coal mines with Adblue storage tanks and dispensers in order to cater for a fleet made up of entirely US Tier 4 non-road diesels has been estimated to be $3.0 million (2012 AUD), which is about 1% of the net benefit. All replacement and combined retrofit and replacement options that include US Tier 4 demonstrate a significant net benefit when including Adblue storage tank and dispenser equipment costs
- **Exhaust aftertreatment retrofit capital, operating and maintenance costs** – the CBA uses cost data from exhaust aftertreatment equipment retrofit suppliers and OEMs. A sensitivity analysis has been done using alternative capital, operating and maintenance costs for the retrofit of DOC and DPF exhaust aftertreatment equipment. The sensitivity concludes that all retrofit and combined retrofit and replacement options demonstrate a net benefit with the higher costs
- **Exhaust aftertreatment weight and space constraints** – the CBA does not include the impact of DPF retrofit on payload and any associated loss in productivity. It is acknowledged that certain equipment may have engineering limitations and these may not be suitable for DPF retrofit. Weight and space constraints associated with retrofitting exhaust aftertreatment equipment should be addressed for each piece of mining equipment used by EPA-licensed coal mines in the PRP process. Since DOC are significantly smaller and lighter than DPF and can generally be accommodated within existing exhaust systems and mufflers, DOC retrofit is unlikely to impact on payload and have any associated loss in productivity
- **Discount rate** - the CBA assumes a discount rate of 7%, which is based on NSW Treasury economic appraisal guidance (NSW Treasury, 2007a, 2007b & 2007c). A sensitivity analysis has been done assuming discount rates of 4% and 10% (NSW Treasury, 2007b). The sensitivity analysis concludes that all retrofit, replacement and combined retrofit and replacement options with the exception of two have net benefits for discount rates ranging from 4% to 10%. Replacement with either US Tier 2 or Tier 3 emission standards compliant equipment have negative net benefits for any discount rate
- **Voluntary equipment replacement strategy** - the CBA assumes the voluntary equipment replacement strategy for the BAU or 'do nothing' option is to purchase equipment with the existing level of emissions certification. As a worst case in order to maximise costs (especially fuel consumption) and minimise benefits (reduction in $PM_{2.5}$ emissions), a sensitivity analysis has been done by assuming the existing fleet performance is either US Tier 1 or Tier 2. In other words, the voluntary equipment replacement strategy for the BAU option is to purchase equipment with either US Tier 1 or Tier 2 level of emissions certification. Assuming the existing fleet performance is either US Tier 1 or Tier 2 provides a suitable basis for evaluating the likely range of net benefits associated with a mandated US Tier 4 replacement strategy. This approach results in a voluntary equipment replacement strategy that has between 75% (US Tier 1) and 50% (US Tier 2) of the $PM_{2.5}$ emissions when compared to BAU. The sensitivity analysis concludes that:
  - if the existing fleet performance is US Tier 2, all retrofit, replacement and combined retrofit and replacement options have net benefits, with the exception of retrofit with active DPF, which has a negative net benefit of -6 million (2012 AUD)

  - if the existing fleet performance is US Tier 1, all retrofit, replacement and combined retrofit and replacement options have net benefits
  - as the natural turnover of the existing fleet tends to either US Tier 2 and/or Tier 3 emission standards compliant equipment, the net benefits associated with a mandated US Tier 4 replacement strategy increase due to improved fuel efficiency.
- **Administration and compliance costs** - the CBA does not include administration and compliance costs. The EPA Information Report (EPA, 2014) presents the costs and benefits associated with introducing US Tier 4 emission standards. Administration and compliance costs have been estimated to account for about 1% of total costs over the 19 year period considered in this CBA and have little effect on the net benefit.

Overall, it is our view the CBA under estimates the net benefits of reducing non-road diesel exhaust emissions and this is largely influenced by future coal mine production, health benefits beyond 2030 and workplace exposure.

This report objectively confirms there are both technically and economically feasible options for reducing non-road diesel exhaust PM emissions. The findings in this report should form the basis for developing PRP in the short term, which are aimed at reducing non-road diesel exhaust emissions at EPA-licensed coal mines in NSW.

For in-service non-road diesel retrofit, an appropriate performance benchmark is at least 25% reduction in PM emissions, which requires the use of either diesel oxidation catalyst (DOC), passive or active diesel particulate filter (passive or active DPF) exhaust emissions aftertreatment equipment, where practicable. To ensure the largest emission reductions and health benefits are achieved, retrofits should be timed to commence with the first scheduled engine rebuild on or after 1 January 2015.

For new replacement non-road diesels, an appropriate performance benchmark is US Tier 4 or equivalent, where practicable. To ensure the largest emission reductions and health benefits are achieved, replacements should be timed to commence with the first scheduled equipment replacement on or after 1 January 2018.

These implementation dates are based on the assumptions used in the CBA. Through the PRP process, reasonable implementation timeframes should be negotiated with EPA-licensed coal mines to account for site specific issues.

It is recommended that all existing and proposed NSW coal mines should conduct a best management practice (BMP) determination to identify the most technically and economically feasible options for reducing non-road diesel exhaust emissions for both existing in-service and new replacement equipment.

Similar to the *Dust Stop* program, this approach has the primary aim of ensuring the most reasonable and feasible PM emissions control options are implemented by each coal mine. All existing EPA-licensed coal mines should be provided with a reasonable timeframe to prepare a report that compares their current operation with international best practice. EPA-licensed coal mines should also be required to report on the practicability of implementing each best practice measure. For any measures found to be practicable, each EPA-licensed coal mine should be required to provide a timetable for implementation. The PRP should only apply to non-road diesels used in surface applications at both open-cut and underground coal mines.

The BMP determination should:
(1) be implemented through a pollution reduction program (PRP), which is enforced through environment protection licence (EPL) conditions
(2) form part of the Environmental Assessment (EA) for proposed coal mine developments, which is directly linked to the air quality impact assessment.

Pollution reduction programs provide a transparent, efficient, equitable, auditable and enforceable manner in which the EPA can exercise its powers under the POEO Act in order to reduce regional and local PM levels by taking into account site specific issues at each EPA-licensed coal mine.

EPA-licensed coal mines are required to submit an annual return form to the EPA. The annual return is a statement of compliance with environment protection licence (EPL) conditions for the preceding 12 months. The non-road diesel performance standards, operation and maintenance requirements for in-service retrofit and new replacement equipment should be included as EPL conditions and compliance determined using the existing annual return process.

The EPA should provide further opportunity for stakeholder comments on the proposed PRP when this report is published.

10 REFERENCES

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