Chief Scientist & Engineer

Final Report on the Independent Review of Rail Coal Dust Emissions Management Practices in the NSW Coal Chain

NSW Chief Scientist & Engineer

August 2016

5 August 2016

The Hon. Mark Speakman SC MP
Minister for the Environment
Minister for Heritage
Assistant Minister for Planning
52 Martin Place
SYDNEY NSW 2000

Dear Minister,

Final Report – Independent Review of Rail Coal Dust Emissions Management Practices in the NSW Coal Chain

In September 2015 you requested that I undertake a review of coal dust emissions management practices in the NSW coal chain. I now submit the final report of that Review.

This report presents the Review's finding and recommendations.

As you would be aware from the Initial Report provided in November 2015, there remains uncertainty about air quality within and near the rail corridor. This Report recommends a path forward to address these uncertainties, which draws on consultations with the community, industry, government and researchers, and is informed by an expert workshop convened for this purpose. Released with this report are two expert papers commissioned about technological advances for sampling and monitoring air emissions from the coal chain in the rail corridor.

In presenting this final report I would like to acknowledge the assistance of many people – in particular industry and community members who took the time to explain their initiatives and concerns, government colleagues who provided technical advice and the experts who made an important contribution towards addressing the issues raised.

Yours sincerely,

Digitally signed by Mary O'Kane
Date: 2016.08.05 08:29:58 +10'00'

Mary O'Kane
Chief Scientist & Engineer

Chief Scientist and Engineer
GPO Box 5477, Sydney NSW 2001, Australia | Tel +61 2 9338 6786
www.chiefscientist.nsw.gov.au

EXECUTIVE SUMMARY

In September 2015 the Minister for the Environment asked the Chief Scientist & Engineer to conduct an independent review of rail coal dust emissions management practices in the NSW Coal Chain (the Review). The Review is part of the Government's response to the NSW Legislative Council Inquiry into the performance of the NSW Environment Protection Authority (EPA).

Community members and groups expressed concerns to the Legislative Council Inquiry and other reviews about the environmental and human health impacts of dust and particle emissions associated with the NSW coal supply chain, particularly in the Hunter region. These concerns in part relate to dust and diesel emissions from coal trains that connect the region's mines to the Port of Newcastle and the effectiveness of current monitoring and management practices.

The Review scoped the scale and nature of the issues through consultations with community, industry stakeholders, EPA staff, and discipline experts, together with a review of available literature. This included studies undertaken locally and internationally to identify the sources of coal dust and emissions in the rail corridor, possible mitigation strategies and analyses of gaps in our knowledge and understanding.

It became evident to the Review that a substantial set of activities has been undertaken over a number of years in the Hunter rail corridor both to measure and to reduce dust and particulates. However, there are no existing studies or sets of studies available to date that can definitively determine if there is a problem associated with dust in the rail corridor. The available studies provide partial information about specific issues.

We do know that the ambient air quality of the Hunter Valley region is well measured and monitored. It compares well with similar regions in Australia and overseas, and mostly meets national goals of the National Environment Protection Measures (NEPM) system, including allowable exceedances. Ambient air quality is generally within the 24-hour average $PM_{2.5}$ and PM_{10} standards, but occasionally particle levels spike and exceed standards because of industrial and domestic activities, proximity to the ocean (sea salt), bushfires or seasonal weather patterns.

However, we know much less about localised air quality, in and near the rail corridor. Current studies suggest that an average of 10% of the deposited dust found in or near the rail corridor is attributable to coal, but much more information is needed. There is a general consensus from the examined studies that dust levels increase when some loaded and unloaded coal and freight trains pass through the corridor; but less well understood is the composition of the dust, its source, quantity, concentration, and pattern and distance of dispersal.

Given the known health impacts of particulate matter, more precision is required about localised air quality in the rail corridor, and the likelihood of its impacting people living and working near the corridor.

The EPA is the main regulator ensuring that operators in the coal chain minimise air pollution, including cost dust emissions. Apart from its regulatory and monitoring role, the EPA has been active in conducting or initiating studies to understand pollution impacts in and near the rail corridor, and in encouraging industry to undertake studies to understand coal train impacts.

Given the insufficient knowledge and data about the amount and distribution of coal dust emissions in the rail corridor, it is not possible to recommend at this stage any additional mitigation measures. This is because there are no reference points against which the effectiveness of the mitigation can be assessed. In addition, without data, no meaningful cost/benefit analysis of the economic, environmental or health impacts of any proposed mitigating measures can be undertaken. That does not mean that current mitigation strategies should be reduced. The Review recommends that the mitigation strategies currently employed be continued, and encourages the adoption of new strategies as information becomes available to enable their effectiveness and net benefit to be assessed.

The lack of knowledge and data is a concern. The Review's main recommendations focus on addressing the gaps in this knowledge.

A workshop of experts convened by the Review proposed a staged approach to gathering the most essential data required to understand coal dust impacts in the rail corridor, working through questions sequentially and using a mix of desktop modelling and in-field measurements. This could be used as the basis for a pilot study which should be designed and implemented for the rail corridor to capture more detailed information and data on particulate levels and profiles within and near the corridor, and whether there are any increases in health risks for people living there.

The Review notes that methodologies can be adapted from international studies on other linear sources, such as roads and freeways. Lessons can also be learned from the 'peak' site approach taken in New Zealand to measuring air quality, and, accordingly, it is proposed that an analysis of potential hotspots be undertaken to inform decisions about the placement of monitors for the pilot study.

Monitoring technology is rapidly advancing and becoming cheaper, smarter and more versatile. A combination of new technologies built to appropriate quality standards has considerable potential for application in the rail corridor.

The Review suggests that NSW needs to adopt a two-pronged approach to air quality monitoring. One prong would maintain the State's current focus on background ambient air quality by way of its well-structured network of NEPM monitors. The second prong would be a more systematic focus on spatial and temporal distribution of air pollutants associated with pollutant-generating sources extending the approach of local monitoring required of some licensed industry activities; and broadening this to other locations and pollution sources which may or may not be subject to licenses. In addition, the data and models derived from the data should be made publicly available in close to real time. An initial focus would be on particulates from local sources in the coal chain (including moving sources such as trains).

FINDING & RECOMMENDATIONS

Finding
The Review is unable to make a formal determination on specific mitigation techniques because there is not enough known about the amount and distribution of particulates in the rail corridor and thus no reference point against which to assess mitigation effectiveness. That said, there is a significant body of literature pointing to moisture as a major factor in reducing dust mobilisation at various components of the coal chain (including for coal trains).

Recommendations
Recommendation 1
It is recommended that NSW adopt a dual approach to ensuring air quality through:

i. the current focus on background ambient air quality by way of a well-structured network of standardised (including NEPM) monitors
ii. a systematic focus on spatial and temporal distribution of air pollutants attributable to specific sources, with an initial focus on particulates from local, though possibly moving, sources (e.g. trains) in the coal chain. This will require banks of dedicated monitors, that form separate networks to the NEPM network, the data from which will allow real-time monitoring and will provide input for new specific local air quality models of pollution from source to where air quality is at background levels.

The data for both foci must be of high quality and publicly available.

Recommendation 2
It is recommended that a pilot study be designed and implemented for the rail corridor that would capture more detailed information and data on whether there is a statistically significant increase in particulate levels within the corridor, how far out from the corridor the particulate profile extends, and whether this would result in an unacceptable increased health risk for people living in the vicinity of the corridor. In order to allow for worst cases, it is suggested that an initial analysis of potential hotspots be undertaken to inform decisions about the placement of the banks of monitors for the pilot.

Recommendation 3
It is recommended that following the pilot study, a process of monitoring pollutant sources at close range be rolled out. This will involve the design, development and deployment of cost-effective monitors for measuring air quality near pollutant sources, and the development of models from the data acquired.

Recommendation 4
It is recommended that all relevant data from industry and government air quality monitors and the associated models be deposited in the NSW Environmental Data Portal and be available to the community (in raw and processed, graphical form) in line with open data principles.

Recommendation 5
It is recommended that rail operator ARTC and all coal producers, coal handlers, coal transporters and companies involved in the coal chain keep all their current mitigation strategies in place (without precluding their further augmentation) until characterisation of the air pollutant profile around the rail corridor is available.

CONTENTS

Figures

1 INTRODUCTION

In June 2014 a Legislative Council Inquiry was established by the General Purpose Standing Committee No. 5 to measure the performance of the NSW Environment Protection Authority (EPA) against its objectives under the *Protection of the Environment Administration Act 1991* (NSW)(General Purpose Standing Committee No. 5, 2015).

In the Inquiry's Recommendation 7, it recommended that, should the Chief Scientist & Engineer suggest all coal trains be fully covered and all empty wagons be washed to reduce coal dust emissions, the EPA amend the relevant licences to adopt the Chief Scientist & Engineer's recommendation.

The NSW Government in August 2015, in responding to the Inquiry's Recommendation 7, indicated that "The Chief Scientist & Engineer has agreed to undertake a review of rail coal dust emissions management practices. This will include review of the work the EPA has undertaken in relation to coal dust emissions along the rail corridor in the Hunter Valley, as well as review of environmental monitoring, the literature, and the environmental management practices of operators using the rail network" (NSW Government, 2015).

In September 2015 the Minister for the Environment provided the Terms of Reference for the Independent Review of Rail Coal Dust Emissions Management Practices in the NSW Coal Chain to the Chief Scientist & Engineer.

The Review submitted an Initial Report in November 2015, and this is its Final Report. Terms of Reference for the Review are at Appendix 1.

1.1 CONTEXT

1.1.1 Coal supply chain

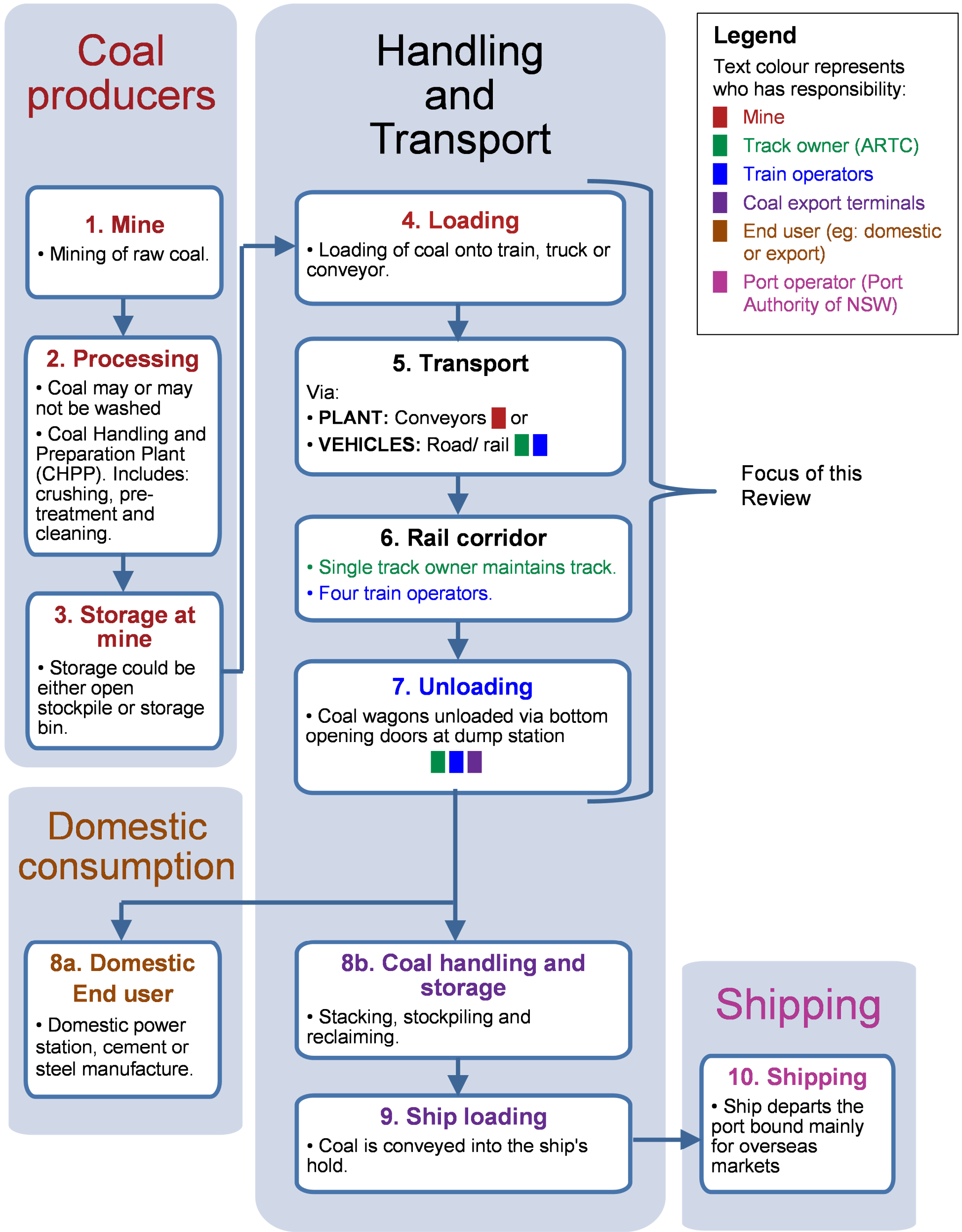
The coal supply chain or simply 'coal chain', describes the steps, points and stages in the extraction, processing, transporting, storing and use or export of coal from the mine to a ship or power plant, as depicted in Figure 1. The coal chain includes mine site, loading, processing, transport (via train, truck or conveyor), shore based handling of coal stockpiles and shipping or feeding of coal to power stations. The rail corridor is defined as the region between the loading activities at the mine site (whether the train or other transport is filled with coal) and the location where the train unloads the coal at the export terminal or power plant. An overview of NSW coal mines, including location, type and distance to the export terminal was included in the Initial Report, and provides an indication of the scale of the relevant regions and coal chains in NSW.

1.1.2 Community concerns

To understand community concerns better, the Review studied the submissions to and outcomes of relevant inquiries, reports and submissions from community groups and industry, and met with key stakeholders.

There has been considerable concern in the Hunter community about the human health and environmental impacts of dust and particulate emissions along the coal supply chain – from the point of extraction to transport and unloading at the Port of Newcastle. These concerns include impacts from particulates of different sizes, diesel emissions from locomotives, and the significant increase in rail movements that has occurred in the last five years. The latter has taken on additional significance in light of the proposed expansion at the Port of Newcastle.

Figure 1: The coal chain



As noted in many studies of air pollution and health, the interaction between the two is complex and dynamic, reflecting multiple sources, pollutants and exposure levels. The difficulties of quantifying and attributing possible health impacts of the rail corridor in smaller communities in the coal chain have clearly contributed to a sense of frustration in the community.

Questions have also been raised about the effectiveness of current monitoring and mitigation strategies, and whether more could and should be done to protect local residents.

1.1.3 Senate Inquiry into the Impacts on Health of Air Quality in Australia

In November 2012, the Senate asked its Community Affairs Committee to inquire and report on the health of air quality in Australia, including the level of particulate matter, its sources and effects; populations most at risk and the causes that put those populations at risk; the standards, monitoring and regulation of air quality at all levels of government; and any other related matters.

A key issue throughout the Committee's inquiry was the potential for coal trains to cause fine particulate and diesel emissions. Evidence presented to the Committee suggested coal trains are a source of pollution; however, the amount and nature of that pollution was a disputed point. The Committee noted dust emissions could also be released during the loading and unloading of coal during transport, whether by truck, train or conveyor.

The pros and cons of a number of mitigation strategies were debated by key stakeholders. The Senate Committee recommended state and territory governments require industry to implement covers on all coal wagon fleets (The Senate, 2013).

1.1.4 Legislative Council Inquiry into the Performance of the NSW Environment Protection Authority

As mentioned in the Introduction, a Legislative Council Inquiry was held in 2014 to investigate the performance of the NSW EPA. It looked at, amongst other things, the EPA's investigations into and public statements about the effects of coal dust pollution in the Hunter.

The Inquiry noted key community concerns, including the potential health and environmental effects of coal dust and other particles produced as a result of mining activity and coal transport; coal dust from trains; and the projected increase in train movements linked to a new coal loader earmarked for the Port of Newcastle.

Submissions to the Inquiry also suggested the EPA had not sufficiently addressed the effects of coal dust pollution, and expressed a lack of confidence in the Authority's independence. Some groups alleged that there were alterations to the recommendations in a draft report produced by Australian Rail Track Corporation (ARTC) at the EPA's direction, about coal dust emissions generated by rail movements prior to its public release.

While the EPA acknowledged that significant amendments were made to the report, it emphasised that in spite of the amendments made, "both the final draft and final report had the same conclusion: there was no appreciable difference between the dust levels measured from the movement of loaded coal trains and other types of freight trains" (General Purpose Standing Committee No. 5, 2015).

1.1.5 National Environment Protection (Ambient Air Quality) Measure (NEPM)

At a national level, air quality standards have been in place for over 15 years; with objectives achieved through four National Environment Protection Measures (NEPMs). The Ambient Air Quality NEPM (AAQ NEPM) establishes standards for criteria pollutants that are monitored and reported as indicators of air quality; including particulate matter.

The AAQ NEPM also sets out requirements for monitoring stations that are part of the national NEPM network to ensure data are captured and reported in a consistent and reliable manner. These requirements include methods for assessing concentrations of different pollutant types, and standards for, and calibration of, instrumentation; stations being accredited by the National Association of Testing Authorities; with siting in accordance with Australian Standards to capture samples that are representative of general air quality in major population centres. This means that these instruments are deliberately not located immediately adjacent to or in source-specific points such as roads. Some stations are nominated as 'trend' stations to monitor long-term changes and are required to be located in one place for at least one decade.

The issues raised in the Parliamentary inquiries were also canvassed in a 2011 review of the AAQ NEPM which made a range of recommendations including improved monitoring in regional areas and research into health impacts of air pollution in regional areas. The pollutants measured under the AAQ NEPM include particulate matter. In 2015 an annual average standard for PM_{10} (25µg/m^3) was introduced and the existing 24-hour average was retained (50µg/m^3). The status of $PM_{2.5}$ changed from advisory reporting to standards (annual average $PM_{2.5}$ 8µg/m^3 and 24-hour average $PM_{2.5}$ 25µg/m^3). These variations were approved in December 2015, at the same time that a National Clean Air Agreement supported by all Australia's Environment Ministers was established.

1.1.6 National Clean Air Agreement

The objectives of the National Clean Air Agreement are "to:

- provide a framework to identify and prioritise specific air quality issues where concentrated effort is needed that will optimise health, environmental and economic outcomes for Australians
- formalise cooperative management of air quality at the national, state and local levels to help develop effective and efficient policy settings that enable swift and informed responses to current and emerging air quality priorities" (Australian Government, 2015).

The Agreement is intended to provide "the flexibility to facilitate targeted cooperation between jurisdictions where it is needed to provide effective and efficient policy responses ..., but otherwise enable state, territory and local governments to act independently in accordance with local needs and priorities" (Australian Government, 2015).

Its key principles are:

- "actions will focus on addressing the most significant current and emerging air quality issues to protect the health of Australians and the environment
- policy decisions on new measures, whether regulatory or non-regulatory, will take account of human health, environmental, and economic considerations
- responses to air quality issues will apply best practice approaches, consider the latest evidence available and identify the most appropriate level of government to take the lead
- policy decisions are relevant, timely, consider available resources, and allow for effective consultation and appropriate lead-in times, balancing the interests of the community as well as businesses in this regard
- air quality management measures delivered are proportionate, efficient and effective, and avoid creating cumulative or overlapping regulatory burdens
- activities are consistent with Australia's international obligations
- the Agreement and endorsed work plan are periodically reviewed to maintain a focus on achievement of desired outcomes and to ensure its continuing relevance" (Australian Government, 2015).

1.2 PROCESS OF THE REVIEW

The first phase of the Review (September-November 2015) was directed at precise understanding of the issues and formal scoping of the problem, in line with the Review's first Term of Reference (see Appendix 1).

A review of available literature was undertaken and a call for public submissions was made. Targeted consultations were undertaken with government agencies, community groups and industry, as well as academic experts, followed by several site visits.

This phase culminated in an Initial Report, produced in November 2015, which provided an overview of the issues raised by stakeholders or found in the literature.

The second phase of the review was directed at identifying practical approaches to addressing the outstanding gaps in our knowledge about coal dust in the rail corridor, and the capabilities that exist to implement these approaches.

A full-day expert workshop was convened by the Chief Scientist & Engineer to discuss the findings of the Initial Review and to obtain advice.

In addition, two expert information papers were commissioned by the Review for the purpose of addressing advances in technology for sampling and monitoring air emissions from the coal chain in the rail corridor.

In this Final Report, the Review has retained most of the information it included in the Initial Report, updated where appropriate. New material arising from review of further studies, from the expert workshop convened by the Review, and from studies commissioned by the Review on new monitoring mechanisms for air quality has been added, as well as recommendations for further action.

1.2.1 Existing studies on coal dust emissions from coal handling and transport

Coal dust emissions from coal handling and transport have been the subject of numerous studies both domestically and internationally over the last decade. NSW initiatives by government agencies, industry, local communities and peak bodies were initially reviewed, followed by studies, reports and regulatory practices in Queensland and jurisdictions overseas to define issues and understand how initiatives elsewhere may apply to NSW. Topic areas included:

- monitoring in or near the rail corridor
- particle characterisation studies
- sources of emissions in the rail corridor
- wind tunnel studies
- nature and effectiveness of mitigation techniques and the specific conditions they were undertaken in
- health studies on effects of air pollution
- studies related to proximity of coal facilities and health effects
- studies to monitor/model the effects of line source pollution (e.g. determine effects on local residents from roads, train lines, etc.).

A table of the studies reviewed, with commentary, is provided at Appendix 3, and a discussion of what the studies show is in Chapter 2.

1.2.2 Submissions

The Review considered all submissions related to coal dust emissions that were previously made to the Senate Inquiry into the Impacts on Health of Air Quality in Australia (2012) and the Legislative Council Inquiry into the Performance of the NSW Environmental Protection Authority (2014). These submissions provided important fundamental insights into the concerns held by the community, interest groups and industry. The Review notes that the majority of issues raised in the two inquiries remain relevant today.

The Review also accepted formal submissions directly to the Review. A list of these is provided at Appendix 6. Submissions (unless otherwise requested) are available on the Review website (www.chiefscientist.nsw.gov.au/reports/review-of-rail-coal-dust-emissions).

1.2.3 Consultations and site visits

The Review has consulted with stakeholders in government, industry and the community, and with research experts. Several site visits were undertaken to view the rail corridor and meet with stakeholders. Discussions have focused on:

- understanding stakeholder views on the source and impact of coal loss and emissions in the rail corridor
- data and rationale underpinning views on mitigation strategies
- historic and current industry and regulatory practices to manage coal loss and emissions

- understanding what initiatives for managing rail coal dust emissions have already been implemented, which initiatives are in progress and those that are still being planned.

A list of meetings undertaken is at Appendix 6.

1.3 STRUCTURE OF THIS REPORT

Chapter 2 provides a brief contextual overview of studies on the impacts of air pollution on human health; reports on what is known about the ambient air quality in the Hunter Valley; and then analyses what is known about the identity and quantity of particulate emissions in and around the rail corridor, their source, how they move in the local environment and any potential impacts.

Chapter 3 provides a brief overview of the role of the Environmental Protection Authority (EPA) in air pollution control and monitoring; describes a number of initiatives undertaken by the EPA and industry to characterise and manage coal emissions; and provides an overview of current and potential dust mitigation strategies.

Chapter 4 discusses the need for further studies to fill the knowledge gaps, and how that could be done; discusses methodologies from other linear sources, such as roads and freeways, that could be applied to rail corridor studies; and looks at changes in monitoring technologies and approaches that could be applied in the NSW context.

Chapter 5 concludes the report with a summary, a finding and the recommendations.

For the purposes of this report, ‘dust’ refers to all particulate matter capable of temporary suspension in the air (Malm, 1999), whilst ‘particulate’ refers to a sub-set of dust with a size of 10 microns or less (i.e. $\leq PM_{10}$).

2 AIR QUALITY AND HEALTH IN THE HUNTER VALLEY: STUDIES

This chapter begins with a brief overview of studies on the impacts of air pollution on human health, to provide a context for what follows.

The later sections analyse and summarise a number of studies which have attempted to identify and quantify the levels of particulate emissions in and around the rail corridor, their source, how they move in the local environment and any potential impacts.

A summary of the studies is at Appendix 3.

2.1 WHY DOES AIR QUALITY MATTER TO HUMAN HEALTH?

Over the last 40 years a significant body of scientific literature has developed on the impacts of various pollutants on human health, including short and long term exposure (Begg, Vos, Barker, Stevenson, Stanley, & Lopez, 2007; Brook et al., 2010; Golder Associates Pty Ltd, 2013; Hime, Cowie, & Marks, 2015; IARC, 2012; Katsouyanni et al., 2001; Lim et al., 2012; NSW Health, 2010; Peters, Skorkovsky, Kotesovec, Brynda, Spix, Wichmann, & Heinrich, 2000; Pope, Burnett, Thurston, Thun, Calle, Krewski, & Godleski, 2004; Pope & Dockery, 2006; WHO, 2013a; WHO Working Group, 2004).

The impact of particulates on human health has been postulated to occur through mechanisms including oxidative stress which can lead to inflammation and toxicity, and airway hyperactivity (Bernstein, Alexis, Barnes, Bernstein, Bernstein, Nel, Peden, Diaz-Sanchez, Tarlo, & Williams, 2004).

This growth in knowledge has been enabled by more sophisticated understanding of the chemical and physical properties and characteristics of substances; advances in instrumentation, monitoring, modelling and computational capacity and development of research methods; and assessment protocols for determining the robustness of studies undertaken as well as risk frameworks and tools (Cohen, Crawford, Stelcer, & Atanacio, 2014; Lane, Levy, Scammell, Patton, Durant, Mwamburi, Zamore, & Brugge, 2015; Lim et al., 2012; Longley, Somervell, & Gray, 2015; Morawska & Moore, 2004; Ostro, Hu, Goldberg, Reynolds, Hertz, Bernstein, & Kleeman, 2015; Rahai, 2008; Sangkapichai, Saphores, Ogunseitan, Ritchie, You, & Lee, 2010; van Donkelaar, Martin, Brauer, Hsu, Kahn, Levy, Lyapustin, Sayer, & Winker, 2016; van Donkelaar, Martin, Brauer, & Boys, 2015). Standards and advisories have been refined as findings emerge and are replicated.

Notwithstanding these advances, gaps in knowledge remain; in part due to the complex nature of pollutants, multiple sources and factors that influence their impact, and the quality and scale of studies required for firm conclusions to be drawn (Pope, Burnett, Thun, Calle, Krewski, Ito, & Thurston, 2002; Raaschou-Nielsen et al., 2013; Simpson, Williams, Petroeschevsky, Best, Morgan, Denison, Hinwood, Neville, & Neller, 2005; Thurston, Ahn, Cromar, Shao, Reynolds, Jerrett, Lim, Shanley, Park, & Hayes, 2015; US EPA, 2009). These complexities have made generalisation of study findings to specific regions or populations difficult. Assumptions and availability of data must also be considered when extrapolating from findings in the literature to a local situation (e.g. some diesel studies draw on occupational exposure to underpin population exposure estimates) and outcomes are not always clear (Dalton, Durrheim, Marks, & Pope, 2014; Hime, 2015; Kunzli, Perez, & Rapp, 2010; Merritt, Cretikos, Smith, & Durrheim, 2013; NSW Health, 2010).

Key to understanding or interpreting human health risk from a chemical or pollutant is to understand both the hazard of the material and the dosage that a person would be exposed to over a time period. Hazard is a function of characteristics such as the chemical nature, particle size and toxicity, while the dosage relates to the quantity of the material, which is dependent on the exposure pathway and concentration inhaled or ingested, along with other factors.

Thus efforts to determine the characteristics of the particles, exposure timeframe, as well as the concentrations and quantities of particles are important in determining the risks to human health. Some materials have a threshold level below which there is a negligible health impact, whereas other materials do not have known minimum threshold levels (safe level of exposure) and therefore no health advisory guideline (ACTAQ, 2014a, 2014b).

For particulate matter, no threshold has been identified below which exposure is not associated with adverse health effects, so considerable focus of regulatory interventions in Australia is made to reduce ambient concentrations of particulate matter in order to provide benefits to public health.

Exposure to both PM_{10} and $PM_{2.5}$, the particulate matter with an equivalent aerodynamic diameter of 10 and 2.5 micrometres (μm) or less respectively, is associated with cardiovascular disease, respiratory disease and mortality and increased symptoms of asthma (Hime et al., 2015). Some associations have also been observed between $PM_{2.5}$ exposure and reproductive and development effects such as low birth weight (Pedersen et al., 2016). The International Agency for Research on Cancer (IARC) has also classified outdoor air pollution including diesel engine exhaust as carcinogenic to humans (IARC, 2012). Sections of the population that would be at higher risk from particulates include older people and people with pre-existing conditions including cardiovascular disease, respiratory disease and diabetes (NSW Health, 2010; Pope & Dockery, 2006).

2.2 WHAT DO WE KNOW ABOUT AMBIENT AIR QUALITY?

Measuring ambient air quality (i.e. the quality of air in the external environment) has been the main focus of air quality regulators across Australia, including NSW, to understand the background levels of pollutants better over the long term. In general, the ambient air quality in Australia and NSW is comparatively good relative to world comparators (see below).

2.2.1 Measurements of ambient pollutant concentrations

Established in 1998, the National Environment Protection (Ambient Air Quality) Measure (AAQ NEPM) is Australia’s national air quality standard, and provides a framework for monitoring and reporting common air pollutants.

Air pollution is composed of both gaseous substances (e.g., carbon monoxide, ozone, nitrogen dioxide) as well as particulates, which can be small particles or liquid droplets. Particulates associated with air quality and pollution are made up of a number of components, including acids (such as nitrates and sulphates), organic chemicals, metals, and soil or dust particles (US EPA, 2016b). Particulates may result from human activities (e.g. vehicle emissions, heating sources, coal dust) or be naturally occurring (e.g. bushfires, dust storms).

Particulates associated with air quality are typically classified based on their size, with PM_{10} representing particles up to 10μm in diameter, and $PM_{2.5}$ being particles up to 2.5μm in diameter. By the nature of its definition, PM_{10} includes particles also in the $PM_{2.5}$ category.

In NSW the ambient monitoring is operated by the Office of Environment and Heritage (OEH). Originally encompassing the Greater Sydney area, the air quality monitoring network has been extended to the Upper Hunter (UHAQMN) and subsequently Newcastle (NLAQMN), representing one of the densest monitored regions in NSW. The Upper Hunter Air Quality Advisory Committee, established under the Protection of the Environment Administration Act 1991 (NSW), advises the EPA on the design and operation of the UHAQMN, and on the management of regional air quality in the upper Hunter Valley. The networks include monitors that are part of the national NEPM reporting framework as well as others located closer to pollution sources such as industrial areas and mining activities. Some of these have been put in place in response to community concerns. Information from this network provides a good indication of background or ambient air quality in the region. Data are regularly updated (some hourly) and are available on the Office of Environment and Heritage (OEH) website (http://www.environment.nsw.gov.au/aqms/aqi.htm).

The quality of the ambient air monitoring network in the Lower and Upper Hunter Valley was a point of consensus in the expert workshop convened by the Review (see Appendix 2), and during the review researchers and members of the public expressed confidence in the data the network produced.

The NSW Air Quality Statement from 2015 found all stations except Wagga Wagga and Stockton met the national daily PM_{10} standard, including allowable exceedances. Stockton was the only station that didn't meet the annual PM_{10} goal across the state, with the higher particle levels at that site attributed to sea spray, mainly during the warmer months (NSW Office of Environment and Heritage, 2016b). The Lower Hunter Particle Characterisation Study supported this assertion, finding 63% of PM_{10} found at Stockton was fresh sea salt, compared with 40% at Mayfield (Hibberd, Keywood, Cohen, Stelcer, Scorgie, & Chang, 2016). Annual $PM_{2.5}$ levels above the standards were recorded at Stockton, Muswellbrook and Carrington. Levels above the $PM_{2.5}$ daily standard were occasionally found at a number of Upper and Lower Hunter sites, with Muswellbrook and Stockton exceeding on 3 days, Mayfield for 2 days and Beresfield, Carrington, and Newcastle on 1 day. In 2015, there was an extreme dust storm in May and bushfires in August that, in addition to wood fires, likely affected some of these outcomes (NSW OEH, 2015).

Figure 2 shows Newcastle air quality for PM_{10} and $PM_{2.5}$ compared with selected international and Australian cities with similar characteristics or industries. Figure 3 shows the performance of Newcastle against selected cities in countries which have some of the highest worldwide reported levels of PM_{10} and $PM_{2.5}$.

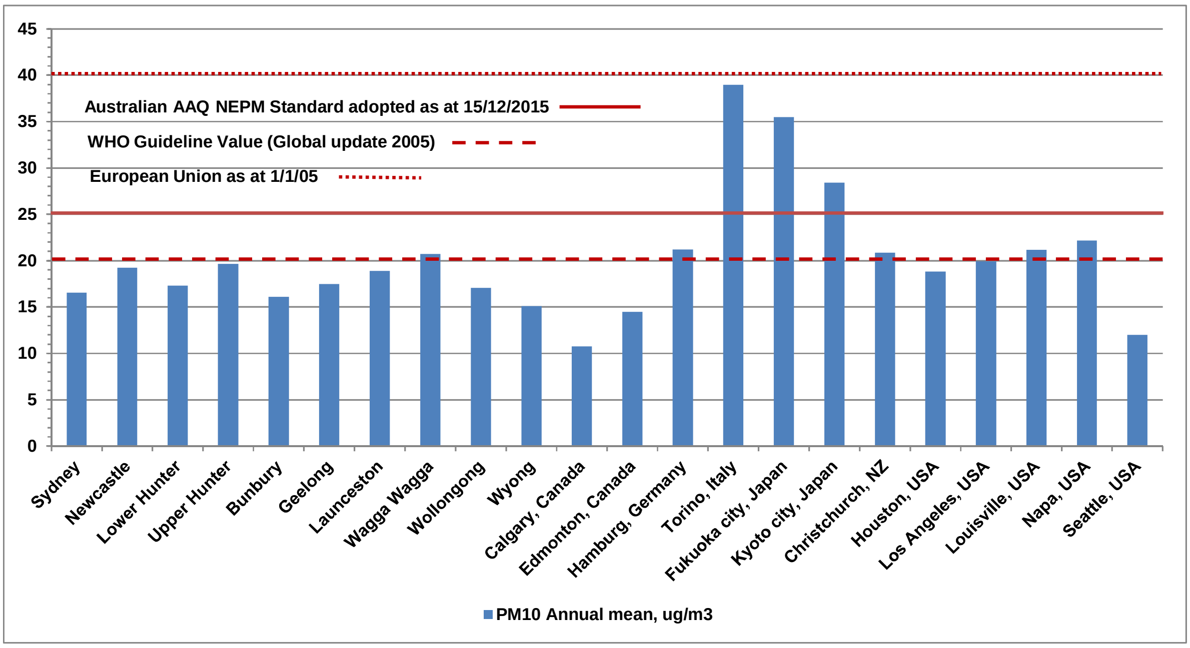
The upper part of Figure 4 shows actual train throughput (i.e. the amount of coal carried by rail in mega tonnes) for Newcastle port from 2005 to 2016.

The lower part of Figure 4 shows the concentrations of 24-hour average PM_{10} and $PM_{2.5}$ from the NSW OEH air quality data. The figure shows that exceedances at Beresfield and Wallsend in $PM_{2.5}$ were only occasional and only slightly above the AAQ NEPM standard apart from the particularly high spikes due to the state-wide dust storm of September 2009 and a major bushfire in October/November 2013. For the Upper Hunter, although Singleton data was only available from December 2010, the plot of both $PM_{2.5}$ and PM_{10} levels show similar levels to the other sites.

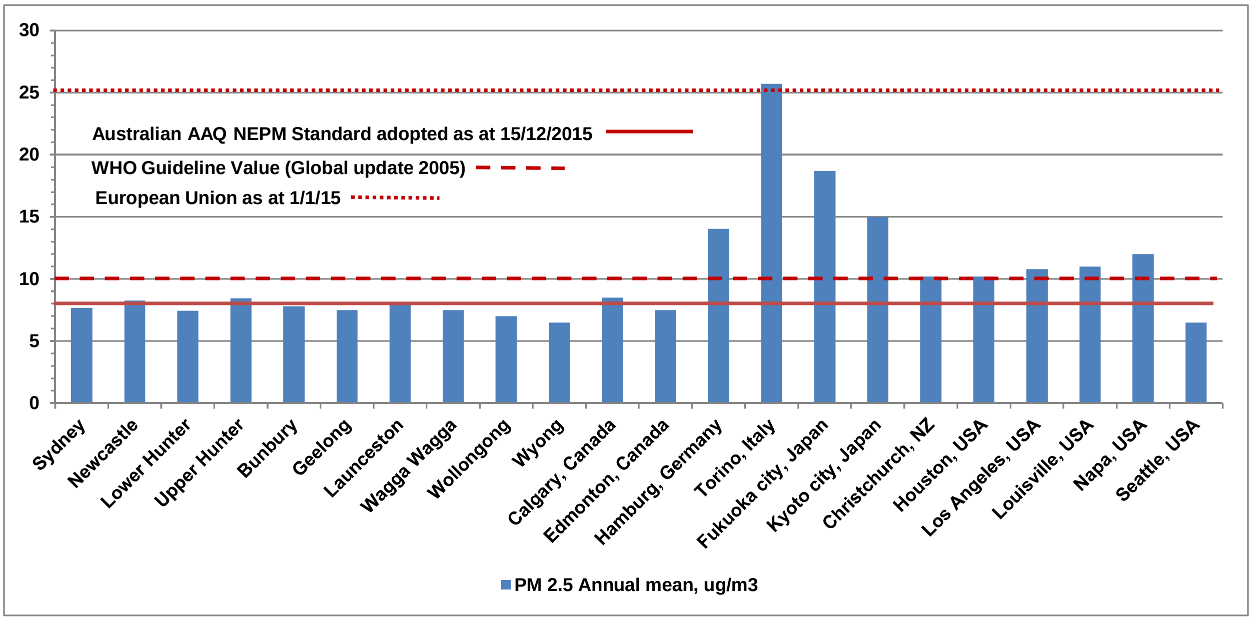
The PM_{10} concentrations show more exceedances than the $PM_{2.5}$ levels, but the high exceedances coincide with the $PM_{2.5}$ ones, for the same reasons. The off-graph exceedances such as those at Newcastle and Singleton on 6 May 2015 were due to a dust storm. Extensive hazard reduction burning also occurred in late August 2015.

It is noted that, despite a 58% increase in coal train movements on the Hunter rail line, from 38 loaded trains per day in 2009 to 60 per day in 2015 (Australian Rail Track Corporation Ltd, 2009, 2015), and an approximate doubling of coal throughput, the ambient air quality in Newcastle has remained fairly constant over this time period (Figure 4) (NSW Office of Environment and Heritage, 2016a). The stable concentrations of both PM_{10} and $PM_{2.5}$ shown in Figure 4 over a period of ten years seem to indicate no apparent, or at least no linear, correlation between the increased coal train movements and throughput through Newcastle and particulate concentrations in the lower Hunter.

Figure 2:
2013-2014 annual mean PM_{10} ($\mu g/m^3$) for various Australian and international cities/regions

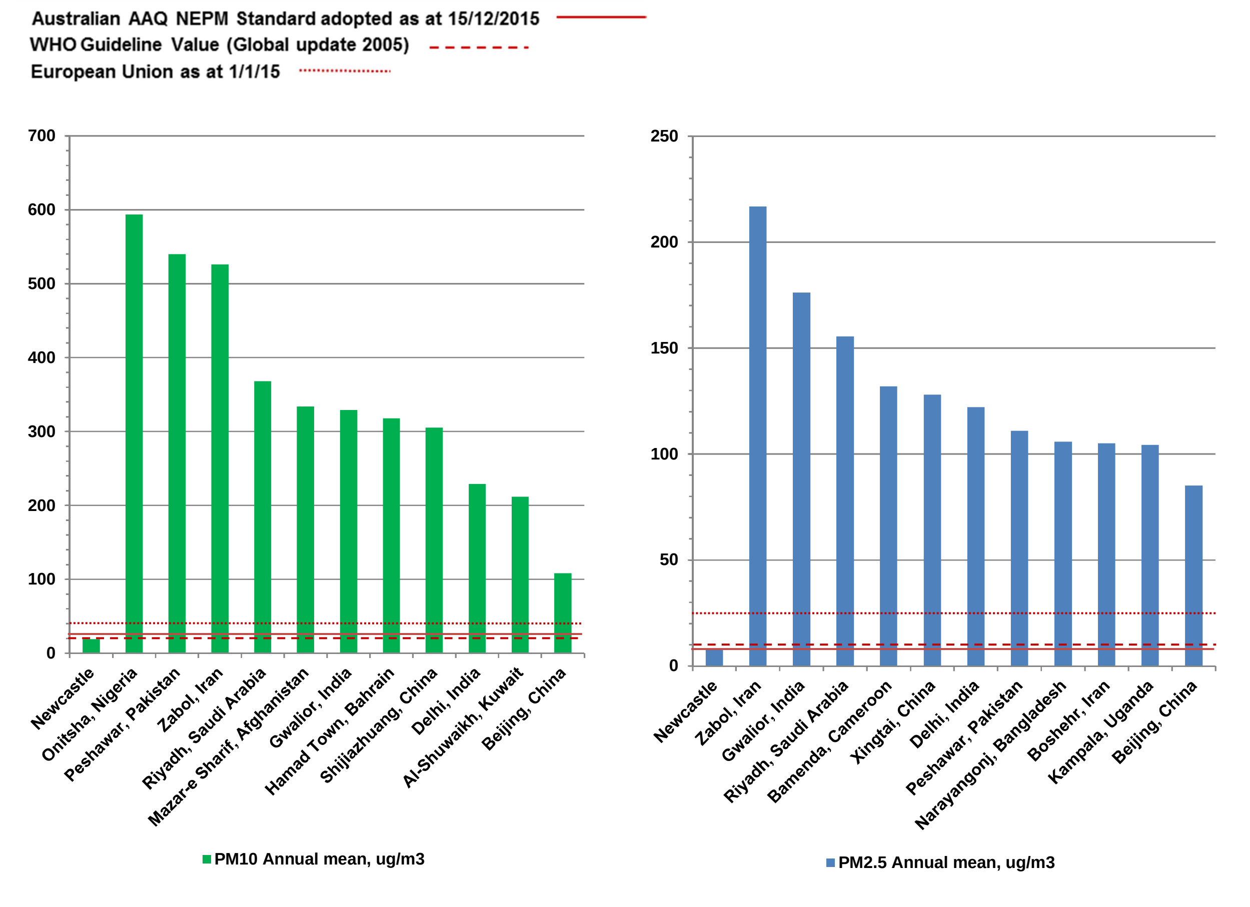


2013-2014 annual mean $PM_{2.5}$ ($\mu g/m^3$) for various Australian and international cities/regions



Note: The WHO database contains either 2013 or 2014 data for different countries, depending upon availability. For some sites, data for $PM_{2.5}$ was converted from direct measurement of PM_{10} or vice versa.
Source: WHO ambient outdoor air pollution database 2016 (http://www.who.int/phe/health_topics/outdoorair/databases/cities/en/)
Selection of comparator cities based on locations with similar characteristics and industries

Figure 3: Annual mean PM_{10} and $PM_{2.5}$ (2013/2014) for various international cities

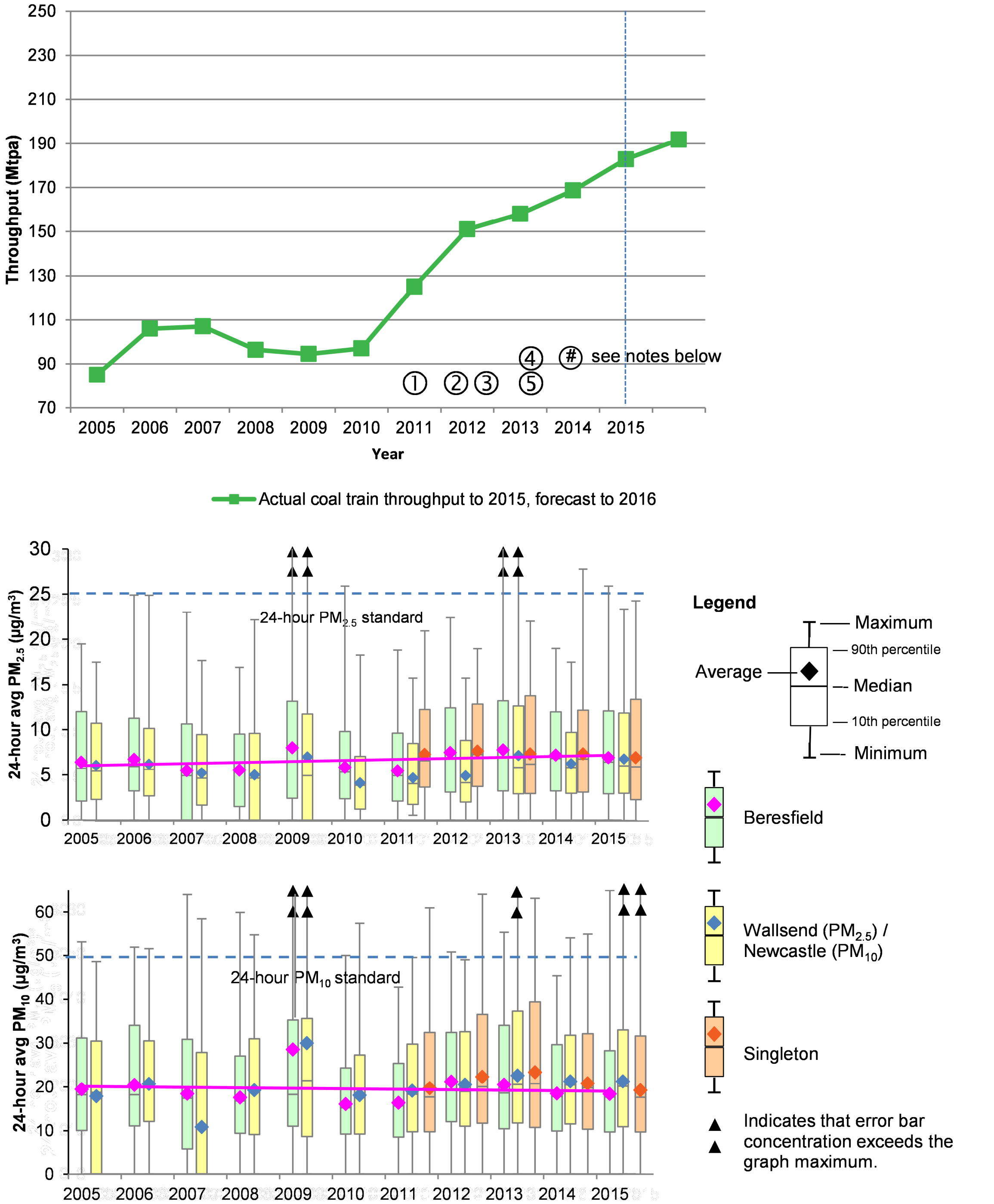


Note: The WHO database contains either 2013 or 2014 data for different countries, depending upon availability. For some sites, data for PM10 was converted from direct measurement of PM2.5 or vice versa.

Source: WHO ambient outdoor air pollution database 2016 (http://www.who.int/phe/health_topics/outdoorair/databases/cities/en/)

Selection of cities based on countries with some of the highest reported pollution levels of PM_{10} and $PM_{2.5}$ worldwide

Figure 4: Train throughput (mega tonnes coal per annum) and 24-hour average PM_{10} and $PM_{2.5}$ Upper and Lower Hunter air emissions for the period 2005 to 2015



Notes:
Numbers refer to port capacity upgrades: [1] 2011 NCIG Stage 1 adds 30Mtpa of port capacity; [2] 2012 PWCS adds 20Mtpa; [3] 2012: NCIG Stage 2 adds 23Mtpa; [4] 2013: PWCS adds 43Mtpa; [5] 2013: NCIG Stage 3 adds 13Mtpa
Rail capacity data sources:
(ARTC, 2005) *Hunter Valley Corridor Capacity Improvement Strategy* [then annually through (ARTC, 2015) *2015-2024 Hunter Valley Corridor Capacity Strategy*].
Legend: To provide an indication of long-term trends, the best-fit straight line through the average 24 hour air quality data for $PM_{2.5}$ and PM_{10} has been taken through the average for Beresfield. The average has been selected as it is less susceptible to the influence of outliers than the median.
Site Daily Average PM_{10} and $PM_{2.5}$ concentrations data source: NSW Office of Environment and Heritage (OEH) air quality data http://www.environment.nsw.gov.au/AQMS/search.htm

2.2.2 Measurements of the composition and source of pollutants in ambient air

Studies have been undertaken in both the Lower and Upper Hunter regions over the last five years.

In 2013, the Upper Hunter Fine Particle Characterisation Study was released (Hibberd, Selleck, Keywood, Cohen, Stelcer, & Atanacio, 2013). The study characterised the major components of $PM_{2.5}$ that communities in the Upper Hunter (Muswellbrook and Singleton) in close proximity to power stations and open cut coal mines are exposed to and whether there were any temporal changes or patterns. The study prepared for NSW Government, undertaken by CSIRO and ANSTO, did not aim to find the specific sources of emissions, and coal was generally not directly measured in the samples, but could have been a component of measured soil. The study reported that of soil made up around 11-12% of the total annual $PM_{2.5}$ mass, compared with the primary factors of secondary sulfate (~20%) for Singleton and wood smoke (~30%) for Muswellbrook, respectively.

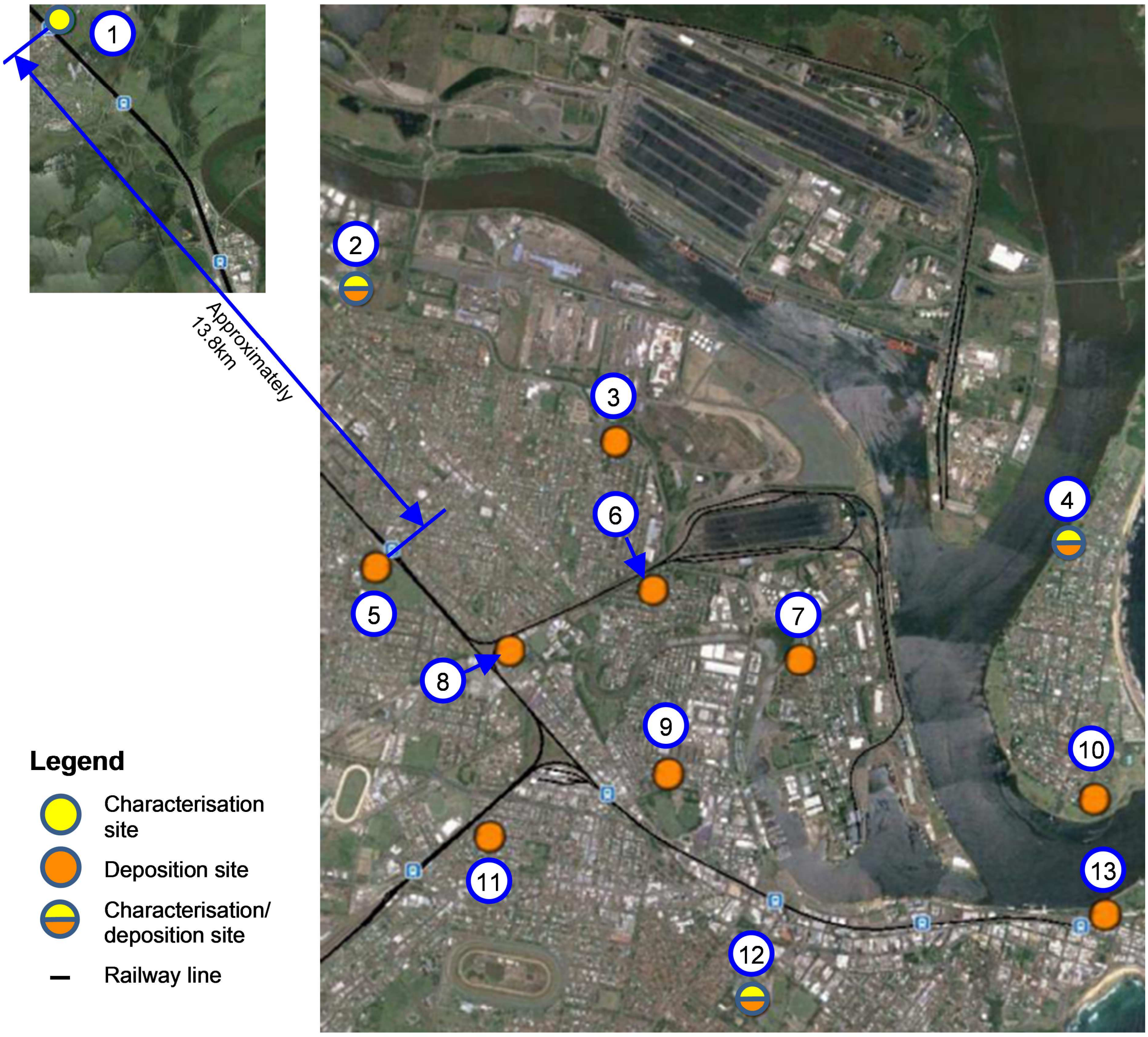
This initial study was followed by two more in the Lower Hunter, both released in April 2016, the Lower Hunter Particle Characterisation Study (Hibberd et al., 2016) and the Lower Hunter Dust Deposition Study (AECOM, 2016). Both studies contribute to overall knowledge of air quality and sources of particle pollution in the Lower Hunter.

The Lower Hunter Particle Characterisation Study (Hibberd et al., 2016) also provides information on coal contribution, though somewhat indirectly. The study collected $PM_{2.5}$ and/or $PM_{2.5\text{-}10}$ samples for a one year period (March 2014-February 2015) at Newcastle ($PM_{2.5}$), Beresfield ($PM_{2.5}$), Mayfield and Stockton (both PM_{10} and $PM_{2.5\text{-}10}$). These sites represented general community exposure and exposure in close proximity to the Port of Newcastle. Figure 6 provides an overview of the monitoring sites.

The report noted that coal was a potential contributor to the measured parameter of light absorbing carbon in the coarser particles ($PM_{2.5\text{-}10}$). Light-absorbing carbon was found to account for about 10% of the coarse particle mass at Mayfield and Stockton, which was noted in the report as the maximum potential contribution of coal to the coarse samples. The report also noted that further analysis would be required to clarify the contribution of coal.

For the fine particles ($PM_{2.5}$) analysis in this same study, coal was attributed to be a potential factor in the measured parameter of soil. The $PM_{2.5}$ composition was analysed across four sites: Newcastle, Beresfield, Mayfield and Stockton, with average soil dust measurement around 10% for all four sites. Within that 10%, four percent was measured as carbon and could be attributed to coal, but the additional 6% could not be coal (Hibberd et al., 2016). A similar study undertaken in Queensland (DSITIA, 2012) analysed dust deposited in or near the rail corridor, finding that mineral dust (soil and rock) was the primary depositional component with coal dust accounting for 10-20% of samples taken at six, twenty and 300m from the tracks (rock and soil made up a minimum of 40%).

Figure 5: Sites used in the Lower Hunter Particle Characterisation and Lower Hunter Dust Deposition studies



Dust deposition and monitoring sites

No.	Name	No.	Name	No.	Name	No.	Name
1	Beresfield	4	Stockton North	7	Carrington	10	Stockton South
2	Mayfield West	5	Waratah	8	Islington	11	Hamilton
3	Mayfield East	6	Tighes Hill	9	Wickham	12	Newcastle
						13	Newcastle East

2.3 WHAT DO WE KNOW ABOUT AIR QUALITY ASSOCIATED WITH THE RAIL CORRIDOR?

Studies initiated by government agencies, industry and community groups have been carried out in NSW and other jurisdictions to understand and characterise coal dust and particulate emissions in and around rail corridors.

A small number of monitoring programs in NSW have measured particulates (TSP, PM_{10}, $PM_{2.5}$, PM_1) in close proximity to rail lines; measured particulate levels associated with different types of trains; and compared results from rail corridor monitors against data from the Hunter's ambient air quality monitoring network.

The Review has examined reports from these monitoring programs and other available studies with a view to providing information about the following:

- sources of dust
- contribution of trains to dust and particulate emissions
- levels of rail corridor particulates compared to ambient levels
- associated human health risks.

A summary of the studies is at Appendix 3.

2.3.1 Sources of dust in the corridor

The transport of coal from mine to port can generate dust and particle emissions from a number of sources. As shown in Figure 6, dust and particles in the corridor can originate from:

- surface of loaded wagons
- leakage from doors of loaded wagons
- parasitic load
- residual coal in empty wagons
- emissions from diesel locomotives
- dust originating from soil within the corridor or from elsewhere
- re-entrainment of spilled coal or other dust in the rail corridor, including through turbulence caused by passing trains.

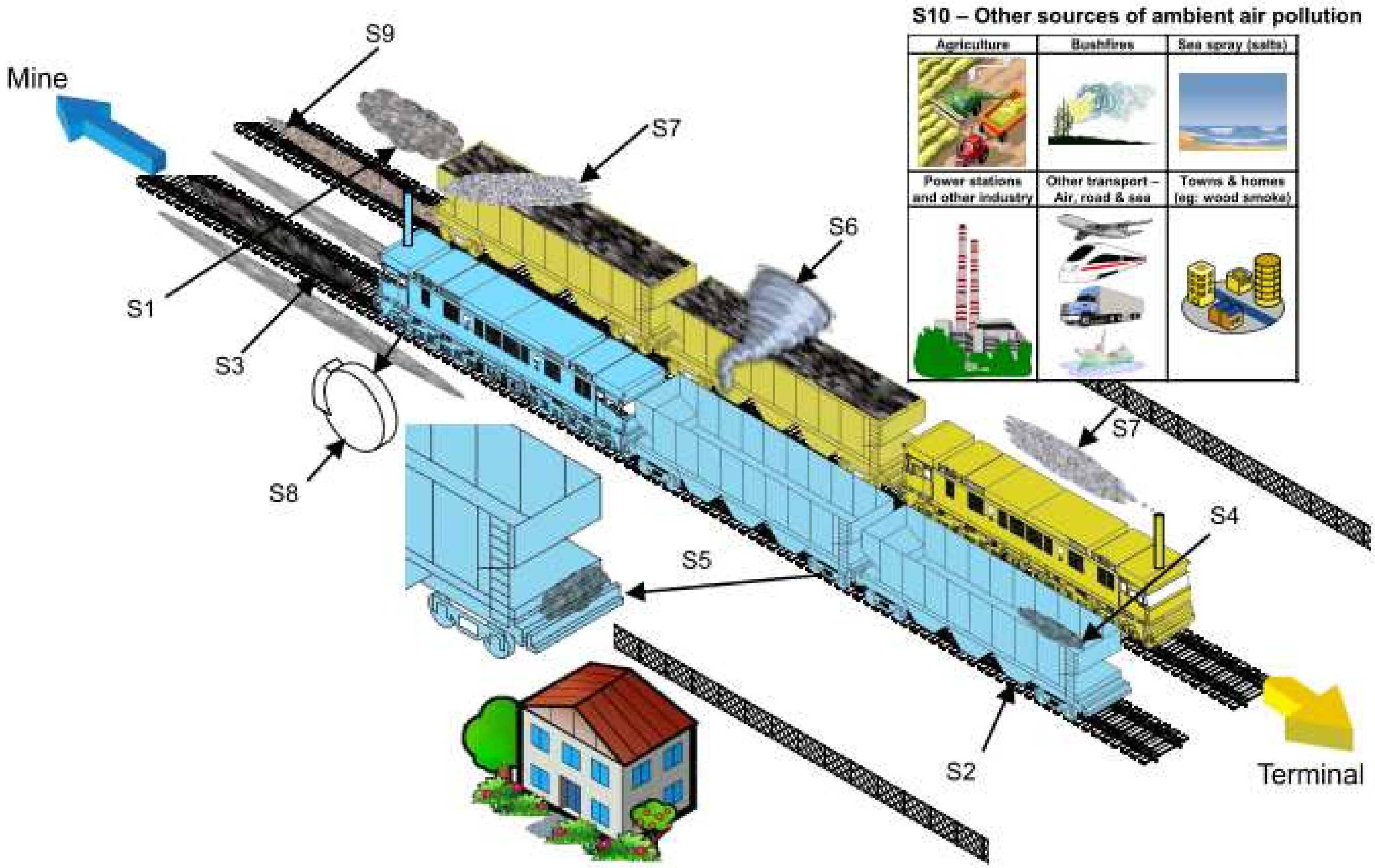
There are various factors that affect the movement of dust into and within the corridor from the above sources – some factors can be controlled (e.g. wagon design; loading and unloading practices), others cannot (e.g. meteorological effects such as wind and rain). This is illustrated in Figure 6.

Studies to determine the origin of the dust – dust deposition studies

The Lower Hunter Dust Deposition Study (AECOM, 2016), which focused on deposited dust at sites in or near the rail corridor, found that coal on average formed 10% of total deposited dust with a range of 0 – 25%. Deposited dust was primarily comprised of larger particles, with some smaller particles, and size was not directly measured. Coal was analysed as black particles, which also included rubber (~4%) and soot (~3%). Soil or rock made up the primary source of dust, averaging 69% of all samples.

This study, taken together with comparable Queensland studies (DSITIA, 2012, 2013), suggests that coal makes up about 10%, possibly 20%, of the dust deposited in the rail corridor.

Figure 6: Potential sources of dust emissions and factors affecting emissions in the rail corridor



Sources

Coal sources
S1 – Coal from surface of loaded wagons
S2 –Coal leakage from doors of loaded or unloaded wagons
S3 – Dust emissions re-entrained from spilled coal in the corridor
S4 – Residual coal in unloaded wagons
S5 – Parasitic load
S6 – Coal due to induced turbulence from two trains passing

Other sources
S7 – Diesel exhaust emissions from locomotives
S8 – Other train emissions (eg: brake dust)
S9 – Re-suspended dust caused by trains passing through the corridor but dust from other sources (e.g.: soil, sea salt etc.)
S10 – Dust from all other ambient sources (agriculture, bushfires, sea salt, power stations/industry, other transport and towns/houses eg. wood smoke)

Factors affecting emissions
Environmental factors: Wind velocity, Wind direction, Precipitation, Temperature, Humidity, Solar radiation, Diurnal effects (i.e. day/night differences), Terrain (this can influence train vibration and locomotive emissions)
Coal/train factors: Coal properties, Length/duration of journey, Loading practices, Train velocity, Wagon design, Wagon maintenance, Locomotive design, Locomotive maintenance, Number of locomotives, Fuel quality, Whether coal is treated or untreated, Acceleration/deceleration rate, Unloading practices, Loaded coal train passing another train

2.3.2 Contribution of coal trains to dust and particulate emissions in the rail corridor

Coal dust can travel into and along the rail corridor due to the movement of coal trains themselves, open wagon surfaces, parasitic coal, and spillage from wagons. Studies have been undertaken to measure whether there is an increase in particulate levels caused by coal and/or other trains and the effects before, during and after the passage of the train on the levels of particulate matter.

Studies to determine whether dust comes from the top of the open coal wagon

In NSW, the ARTC, as a result of the Pollution Reduction Program requirements of its Environmental Protection Licence (EPL), commissioned a two-month, single location trackside monitoring program at Metford in the Hunter Valley to ascertain dust levels in the corridor. A key driver for the study was determining whether passing uncovered coal trains resulted in an increase in the amount of dust measured by a monitor compared with other train types. Results from the study indicated that particulate levels rose as a result of coal trains passing the monitor (Katestone Environmental Pty Ltd, 2013). The conclusions drawn from the study are informing the debate on the source of emissions from coal trains and the dataset has been the focus of several analyses. There was a degree of controversy generated around the study and questions about the robustness of the study design and the original statistical analysis. The data was reassessed independently by several experts, including Professor Louise Ryan from University of Technology Sydney.

Ryan found:

- that freight and coal trains were associated with increased levels of particulates when passing, by approximately 10% above baseline levels. Particulate levels associated with the passing of unloaded coal trains were higher (not statistically significantly) than those associated with loaded coal trains and freight trains. She postulated that diesel emissions may have been a larger contributor to PM levels, particularly as the levels were also elevated for $PM_{2.5}$ (smaller particles from combustion) and the lack of significantly higher results from loaded coal versus other types of trains (Ryan & Wand, 2014)
- upon reanalysis, when additional rainfall data was provided, that potentially the re-entrainment of particles and dust already on the line was a more significant factor than the dust coming from the tops of wagons, as the amount of dust measured in the air by the monitor was influenced by whether it had rained the previous day in the nearby town of Maitland (Ryan & Malecki, 2015)
- it was difficult to generalise results from a single trackside monitor (Ryan & Malecki, 2015).

Ryan's findings are in contrast to a widely cited report from Queensland that estimated 80% of coal dust emissions come from the surface of exposed wagons (Connell Hatch, 2008).

From a health perspective it should also be borne in mind that due to constraints (time and limited data and study design), the re-analyses assessed relative particle concentrations (increases) from passing trains, but not whether PM_{10} or $PM_{2.5}$ NEPM standards were met nor did it assess the level of total particulates that people may have been exposed to.

Advice was sought from NSW Health on potential health impacts of spikes in dust levels that occur with some passing trains. NSW Health's response noted that standards are only available for a 24-hour average and not for shorter periods. "However, the high frequency of trains suggests that the periods between spikes may be short and that 24 hour and yearly averaged levels may represent, somewhat, the exposure", the response stated. It also noted, somewhat reflecting the third observation of Ryan (above), that many of the referenced studies were based on a dataset from a single air pollution monitor and queried whether these data may be insufficient to estimate exposure to residents needs to be considered. The correspondence noted that "information on residents' proximity to rail lines as well as dispersion models for those further away would be helpful to consider more accurately the likely exposures generated".

Participants in the expert workshop convened by the Review (see Appendix 2) also noted findings from previous studies that in the denser urban areas in Newcastle there are few 'no train' periods and elevated dust levels may persist for some time after the train has passed. In essence, this raises the possibility that in the denser areas, concentrations are constantly above baseline and any differentiation of a 'spike effect' may or may not be meaningful.

Other confounders are the difficulty of interpreting studies that capture repeated peak concentrations. While chamber studies may provide some information, these will not provide data on the impacts of repeat spikes. Further work on the issue of peak concentrations may be informed during the development of, or by the outcomes of, the proposed approach of conducting localised studies (see Chapter 4).

A Queensland Government commissioned review in Tennyson noted that trains (see Appendix 3), irrespective of type, increased particulate levels but did not exceed PM_{10} standards (DSITIA, 2012). As the major deposited amount found was soil and rock, the study concluded that the re-entrainment of ground/surface dust as a result of the train passing was the primary contributor to an increase in airborne particulate matter. The latter conclusion was, for the most part, echoed in another Queensland Government study to evaluate the effectiveness of the veneering program (DSITIA, 2013).

Community studies have also found that particulate concentrations increased when trains passed. According to these studies, the amount by which the concentration of dust increases does appear to vary with train type, or between trains of a particular category. This was illustrated in some of the data provided to the Review by authors of the Coal Terminal Action Group (CTAG) Coal Train Signature Study (Higginbotham, Ewald, Mozeley, & Whelan, 2013).

The CTAG Study (NSW) reported that 81% of coal trains produced a recognisable signature with pollution levels increasing up to 13 times when coal trains pass. Signatures varied, but the highest increase was for an unloaded train (Higginbotham et al., 2013).

Clean Air Queensland undertook a similar community-based study along the West Moreton rail line to determine the pollution signature from passing trains. Eight signatures were reported representing the worst-case scenarios. Loaded trains were found to increase PM_{10} levels between 500-1,000% over pre-train levels; the increase for unloaded was 500-900% and freight 100-150%. The intensity and the peak varied significantly between different coal trains. All the coal trains studied were assumed to be veneered (Kane, 2015).

Field and wind tunnel studies

A number of wind tunnel studies have been undertaken in an attempt to quantify the amount of dust that may disperse from the top of an open coal wagon and the aerodynamics associated with the height and configuration of the load.

Ferreira, Viegas, and Sousa (2003) conducted tests of coal dust emitted from coal trains. They placed dust-collecting instruments onto wagons carrying coal from a port to a power station in Portugal. The study conducted measurement of TSP emissions from coal wagons over a simulated 350km journey, and found that a 60t semi-covered wagon would lose approximately 0.001% of its load with an undisturbed flow velocity of 13.4m/s (48.2km/hr). The use of a semi-cover system, despite the existence of a 1m wide gap along the upper part of the wagon, significantly reduced the amount of dust released. Connell Hatch in its review of Ferreira et al mentioned that overall the train transport distances and climatic conditions during the sampling were comparable to conditions in the Queensland study area.

In a later study, Ferreira and Vaz (2004) used scale model trains in a wind tunnel and compared completely open coal wagons with 'semi-cover' systems partially covering the upper surface to show that partially covering coal cars reduced dust emissions by more than 80%.

Two programs of wind tunnel testing have recently been undertaken in NSW by industry to determine potential lift off of coal from the surface of wagons for various NSW coal types and the effectiveness of surface treatments. The testing concluded the moisture content of the tested coal was high enough to indicate low risk of dust lift off under normal NSW operating conditions, where the actual moisture level was above the Dust Extinction Moisture level (DEM). The DEM level is defined in Australian Standard AS4156.6 as the moisture content at which the dust/moisture relationship is 'optimal'. In practice this means minimal dust generation. At the time of this Review, those studies were not publically available.

National track operator ARTC is also investigating the viability of undertaking an opacity monitoring study across the top of coal wagons in the corridor. This would be to validate the results of the wind tunnel testing and to identify trains that are emitting higher levels of visible dust (NSW Minerals Council, 2016). This opacity monitoring method has been previously used in Queensland for a similar purpose.

Studies to determine whether dust falls from doors underneath the coal wagon
Studies have been undertaken to attempt to determine the extent of loss from doors underneath the coal wagon, including the Coal Leakage from Kwik-Drop Doors - Coal Loss Management Project (Aurecon Hatch, 2009). Undertaken in Queensland, the study identified a range of variables that could influence whether and how much coal would be lost from the doors, including coal type and rank, moisture content and meteorological conditions and wagon design.

The ARTC, in conjunction with stakeholders and the NSW EPA, is currently investigating coal deposition on rail corridor infrastructure, under the PRP 5.0 Investigation of Coal Loss from Rail Wagons on the ARTC Network. There are two components to this work:

- a drop-sheet study: matting placed over the ballast, to enable the capture and monitoring of coal deposition, was installed at four sites on departure roads that were identified as areas that receive high rates of deposition
- a vacuuming trial: industrial vacuuming of three turnouts that were identified as having high rates of deposition, and a straight 100m section of track.

Locations were deliberately selected at sites with higher levels of coal deposition and should not be taken as indicative of general rail corridor conditions in the rest of the system.

Whilst initial observations from the drop-sheet study suggest that there is a large variability in the rates of deposition at the different sites, the data also indicate that there is a consistency in the range of particles deposited. In particular, deposited particles are predominantly in the gravel classification (2-60mm) or, at the turnouts, in the cobble classification (> 60mm).

Initial results from the vacuuming trials indicate that, although vacuuming is partially effective at removing deposited coal, the primary benefit is for the operational reliability of critical rail components, such as turnouts and crossovers. Further, vacuuming does not target the sources of coal deposition.

2.3.3 Whether particulate levels are higher in the rail corridor than in background locations

There are few studies in NSW that have measured how background or ambient levels compare with baseline dust levels in the corridor.

The Review considered, among others:

- a NSW community monitoring study that provided a snapshot of air quality close to the coal facilities compared with ambient that found higher levels of particulates at the study monitoring sites (Rogers, Whelan, & Mozeley, 2013). The study used portable air monitors across 12 sites (reported on 11) in the Lower Hunter measuring

PM_1, $PM_{2.5}$, and PM_{10}, and found PM_{10} levels were consistently higher than readings from selected EPA monitoring sites. PM_{10} was also found to be above NEPM standard at a majority of those sites, with one site also exceeding NEPM standards for $PM_{2.5}$. In particular:

  - for 24 hour PM_{10} the study reported results across 11 sites which included 56 total sample days. It found a total of 17 readings above 50μg/m^3 (NEPM 24 hour PM_{10} standard) across 7 sites
  - for 24 hour $PM_{2.5}$ the study reported results across 11 sites which included 56 total sample days. It found a total of 1 reading above 25μg/m^3 (NEPM 24 hour $PM_{2.5}$ standard) across the sites
  - the study also compared their results to 4 other monitors (1 Industry and 3 EPA) in the region during the same period, these monitors showed no exceedances (Rogers et al., 2013)

- local PM_{10} levels, from the Review's assessment of data provided in a Queensland study, appear to be slightly higher than ambient levels, but also appear to be within NEPM air quality standards (DSITIA, 2012).

2.3.4 Dispersion of dust and particulate emissions beyond the corridor

There does not seem to be much data available on the dispersion of coal dust and related particulate matter from the rail corridor into the surrounding community. A number of studies have looked at the spatial extent of air pollution (including particulates) from mobile sources but these mostly relate to roads (Zhou & Levy, 2007) and for rail yards relate to diesel pollution (see Appendix 3).

There is a body of general knowledge about how particles travel through the air, but this alone does not tell a complete story. The World Health Organisation says that particles between 0.1μm–1μm can stay in the atmosphere for days or weeks and can be transported over long distances, i.e. thousands of kilometres. Coarser particles typically travel less than 10 km from place of generation but under some circumstances travel as far as 1,000 km (Joint WHO/Convention Task Force on the Health Aspects of Air Pollution, 2006).

Particle dispersion modelling may go some way towards helping to describe the movement of particles over an area from source to receptor. To date, the Review is not aware of any relevant study having been undertaken in the NSW rail corridor, and there are limitations as to what conclusions can be drawn from available information from sources such as:

- the Queensland Rail study which undertook dispersion modelling using a Gaussian line source model with results stating it was unlikely there would be any exceedances of TSP and PM_{10} beyond the rail corridor; however, the inputs and assumptions to the model are not described in detail in the report (Connell Hatch, 2008)
- the fine particle characterisation study by the NSW EPA in the Upper Hunter towns of Muswellbrook and Singleton which showed 10-14% of $PM_{2.5}$ could be coal (as fugitive coal dust in soil), but it could not categorically determine the source, whether from a mine, coal train, power station, etc. Other sources like wood smoke and secondary sulphate were larger contributors.
- the Lower Hunter Characterisation Study, focussing on ambient sites, (see Section 2.3.1. above).

2.3.5 Expert workshop on air quality in the rail corridor

Following the Review's Initial Report, the Review convened a workshop of 11 experts to consider the questions raised in that report, which were based on the same analysis that is provided above.

The participants noted that there is no common understanding of the emission rates, sources, variable contribution from different sources (including what proportion is coal) or particle size and how dust is dispersed and deposited. Further, while studies show some dust ‘signatures’ with the passage of trains, the participants noted that it remains unclear if the increment of change in dust levels and the dispersion of the plume is sufficient to affect health above that from background levels.

2.4 SUMMARY OF THIS CHAPTER

The ambient air quality of the Hunter Valley region is well measured and monitored. It compares well with similar regions in Australia and overseas, and meets national goals, including allowable exceedances. Ambient air quality is generally within the 24-hour $PM_{2.5}$ and PM_{10} standards, but occasionally particle levels spike because of industrial activities, proximity to the ocean (sea salt), bushfires or seasonal weather patterns.

However, much less is known about localised air quality, in and near the rail corridor. Current studies suggest that about 10% of the deposited dust found in the rail corridor is attributable to coal, but much more knowledge is needed. There is a general consensus from the examined studies that dust levels increase when some trains pass through the corridor; but there is uncertainty about how much and why. Is the dust being emitted from uncovered wagons, loaded or unloaded, or is it settled dust being stirred up by passing trains, or is it a combination of sources and dispersal routes? If the dust along the corridor, or some parts of the corridor, is at levels that exceed air quality standards, at what distance out from the corridor do they cease to be an issue?

Given the known health impacts of particulate matter, more precision is required about localised air quality in the rail corridor, and the likelihood of its impacting on people living and working near the corridor.

3 HOW COAL CHAIN IMPACTS ARE CURRENTLY REGULATED, MANAGED AND MONITORED

This chapter provides a brief overview of the role of the Environmental Protection Authority (EPA) in air pollution control and monitoring; describes a number of initiatives undertaken by the EPA and industry to characterise and manage coal emissions; and provides an overview of current and potential dust mitigation strategies.

3.1 ROLE OF EPA

As described in Chapter 1, Australia has a national air quality system, which is implemented at national, state and local government levels.

In NSW, the NSW EPA has lead regulatory responsibility for issues and activities affecting air quality, including the Hunter Valley. The agency may use licensing, compliance, investigation, enforcement actions, research and special initiatives to impact environmental outcomes and meet regulatory responsibilities mandated through their respective Acts and regulations.

The *Protection of the Environment Administration Act* 1991 (NSW) s6 sets out the EPA's objectives, which include under s6(a) to protect, restore and enhance the quality of the environment "having regard to the need to maintain ecologically sustainable development"; and under s6(b) promoting pollution prevention; adopting the principle of reducing to harmless levels the discharge of substances likely to cause harm into air, water or land; adopting minimum standards and setting mandatory targets for environmental improvement. The section also includes promoting community involvement in decisions about environmental matters, ensuring the community has access to relevant information and conducting public education programs.

S6(2) provides that for the purposes of s6(1), ecologically sustainable development requires the effective integration of economic and environmental considerations achieved through the precautionary principle, inter-generational equity, conservation of biological diversity and improved valuation, pricing and incentive mechanisms for environmental assets, the latter including 'polluter pays'.

These directions are given practical effect through the *Protection of the Environment Operations Act 1997* (NSW) (the POEO Act) and related regulations. The POEO Act empowers the EPA to license activities (environment protection licences or EPLs) and make particular conditions, e.g. requiring pollution studies or reduction programs.

The EPL system is based on an outcome, load and risk based approach with an emphasis on best practice. Pollution Studies and Pollution Reduction Programs (PRPs) are frequently used as part of the licensing regime to assess and respond to significant issues and management practices. The EPA must review each EPL at least once every five years.

Railway system activities in NSW are specifically captured in Schedule 1, cl 33 of the POEO Act and are defined as including at 1(b) the operation of rolling stock on track. Rolling stock at cl 4 is taken to be operated by the occupier of the land on which the track is situated. 'Track' is defined as forming part of or consisting of a network of more than 30 km.

Under current arrangements, environmental responsibility of all rail activities is held by the "below rail" operator. The "below rail" operator is the Australian Rail Track Corporation (ARTC), a Federal Government-owned corporation that leases the Hunter Valley Coal Chain network from the Government of NSW. As the "below rail" operator, it is subject to an EPL. Coal export terminals are also required to comply with their EPL obligations, including

PWCS Carrington, PWCS Kooragang, Port Kembla and the NCIG coal export terminals. Mines, including those that load coal trains, also are required to hold and comply with EPLs.

3.2 EPA INITIATIVES TO CHARACTERISE AND MANAGE EMISSIONS FROM COAL TRANSPORT

As part of its regulatory role, the EPA has undertaken numerous initiatives over the past decade to learn more about the impact of the coal industry, including the handling and transport of coal, on air pollution, with a view to taking positive steps to reduce emissions where feasible and practical (Figures 7, 8). Ongoing programs that began as early as 2009, like the Interagency Taskforce on Air Quality in the Hunter, the *Dust Stop* program for open cut coal mines, and the Upper Hunter Air Quality Advisory Committee, have focused effort on reducing emissions from coal mining operations.

More recently, the EPA has continued initiatives and studies specifically focusing on emissions from the handling and transport of coal across the region. This work has attempted to identify and quantify the levels of particulates in and around the rail corridor, their source and how they move in the local environment. Initiatives have included a compliance audit of coal train loading and unloading facilities, which has led to operating and equipment improvements at a number of facilities; a review of regulation of railway systems activities under the Protection of the Environment Operations Act 1997 (NSW) with the EPA recommending that above track rail operators be licensed; and a project to measure and reduce emissions from new and in-service locomotives (see Section 3.2.4 below).

3.2.1 Regulatory reforms

Over the past three years the NSW EPA has reviewed the regulatory framework for rail construction and operations, proposing legislative amendments to require rolling stock operators to hold an environmental protection licence (EPL) to improve accountability for emissions (NSW EPA, 2014a).

While mining and port operators have been required to hold EPLs, rolling stock operators have not been subject to the same regime. From a supply chain perspective, the effect of the definition is that primary responsibility for environmental performance vests with the network (track) operators, with rolling stock operators (carriers) captured through secondary (contractual) arrangements between them and the network operator. A 2014 Position paper identified limitations with these arrangements, including inefficiencies and enforceability of environmental obligations through secondary and essentially commercial arrangements (NSW EPA, 2014b).

At the time of this report, draft amendments to Schedule 1 of the POEO Act had been released for public consultation. It is understood that as part of the reform process working groups will be established to inform the content of proposed licences including requirements for locomotive noise and air emissions, with the view to implementation by late 2017 (NSW EPA, 2016a). A cost-benefit analysis to assess the economic and social costs and benefits of the proposed regulatory options was released in May 2016 (NSW EPA, 2016b).

3.2.2 Licencing developments

Changing EPA licencing provisions for the ARTC and port operators over time reflect increasing attention not only to minimising dust emissions, but also their dispersion outside the area of activity (Figure 7).

Department of Planning and Environment approvals also include increasingly coordinated approach to monitoring dust emissions with explicit requirements for preventing and minimising dust emissions in the coal chain. For example, as part of the Kooragang Coal Terminal modification (06_0189 MOD 1) development consent approval the proponent (PWCS) was required to develop and submit for the approval of the Director General of the

Department of Planning and the EPA an Ambient Dust Monitoring Program (including an Integrated Air Quality Monitoring Network, developed in consultation with the owner operator of the nearby NCIG Coal Export Terminal), and an Operation Environmental Management Plan which included a Dust Management Plan. More recently, the Port Waratah Coal Terminal 4 determination (D364/15) includes more detailed requirements for the Air Quality Management Plan and a requirement for a Coal Wagon Cleaning protocol. This Protocol is to give effect to the 'Dust Management condition B6 which states: "The proponent shall ensure that coal wagons leaving the site are completely empty, with dump doors fully closed and sufficiently clean so that there is no visible evidence of coal deposition on the ballast around the rail tracks from trains leaving the site" (NSW Planning Assessment Commission, 2015). Similarly, the Duralie Extension Project approval includes a requirement under Additional Dust Mitigation Measures at s21A that "within 3 months of the date of approval, a study of the dust emissions from the laden trains associated with the Project is to be submitted." (NSW Planning and Environment, 2012).

Figure 7: Dust-related EPL conditions over time for the ARTC and port operator

ARTC License condition [dust] 2001-13
O4 Air: 04.1: Significant dust generating activities on the premises must be managed in a proper and efficient manner to minimise dust emissions from the premises.

ARTC License condition [dust] Dec 2013
03.11 Air: The licensee must minimise the emission of dust at the premises and prevent its emission from the premises, to the greatest extent practicable

ARTC License condition [dust] Jan 2014
O3 Dust O3.1 Air: Significant dust generating activities on the premises must be managed in a proper and efficient manner to minimise dust emissions from the premises

ARTC License [dust] condition Apr 2016
O3 Dust O3.1 Air: Dust generating activities on the premises must be managed to minimise the generation of dust and prevent it going offsite so far as reasonably practicable

PORT OPERATOR License condition [dust] 2014
O3 Dust O3.1 The premises must be maintained in a condition which minimises or prevents the emission of dust from the premises

PORT OPERATOR License condition [dust] 2015
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 operations and activities occurring at the premises must be carried out in a manner that will minimise the emission of dust from the premises. O3.3: Trucks entering and leaving the premises that are carrying loads of dust generating materials must have their loads covered at all times, except during loading and unloading

3.2.3 Management practices

Standard EPL requirements to maintain plant and equipment "in a proper and efficient manner" and for licensed activities "to be carried out in a competent manner" underpin major audit programs undertaken by the EPA. As previously noted, the EPA approach to licensing is outcomes based; and so in general it does not require specific mitigation measures but rather, requires license holders to use appropriate methods to achieve an outcome, however this does not preclude the EPA imposing specific requirements as appropriate (see Appendix 4).

The EPA completed a compliance audit program of 11 coal train loading and four unloading facilities in NSW in 2014. Ten of the loading facilities and three of the unloading facilities were in the Hunter region. The audit focused on avenues for coal loss during rail transport (leaks, spills, dust emissions) and the management practices to minimise them.

The audit found a total of 26 non-compliances. There were non-compliances around train loading activities to minimise or prevent leaks and spills, coal deposition on the exterior of wagons, or emissions from the tops of wagons during transit. Unloading facilities generally rated better (NSW EPA, 2014a).

Notably, in relation to the port operators when considering whether "Carrying out train unloading activities in a manner which minimises or prevents coal dust emissions from the interior of empty wagons during rail transport", the audit made a determination of 'compliant' in relation to "Large amounts (tonnes to tens of tonnes per wagon) of carry back coal remaining in wagons" but a finding of "not determined" in relation to "Small amounts of carry back coal in the form of small accumulations (kilograms to hundreds of kilograms per wagon) and fine coal particles remaining in wagons".

The EPA undertook follow-up inspections of all premises that had non-compliances. Considerable progress had been made at premises to address the issues raised by the audit. These changes include installation of additional loading infrastructure and monitoring equipment, updated procedures and enhanced training of staff.

In 2014, the EPA commissioned a literature review by Katestone Environmental that focused on coal dust management practices in NSW and other jurisdictions. This report noted that the effectiveness of most management practices was not well documented in the current literature. A review of the studies to date found that while dust levels tend to increase when trains pass, when compared against NEPM standards, particulate measurements did not exceed the standards. It is important to note that the monitors used in trackside studies have varied; and results would vary depending upon equipment and methods used; making direct comparisons difficult.

3.2.4 Use of Pollution Reduction Programs

The EPA has mandated several Pollution Reduction Programs (PRPs) onto the ARTC since 2010 with the aim of reducing coal dust emissions from coal rail transport. The first piece of work by the ARTC, Impacts of Fugitive Dust from coal trains in NSW – Stage 1 gap analysis, contextualised the issue for NSW and led into a trackside monitoring program to measure particulate levels when trains pass (Figure 8).

Building on that initial work, the EPA imposed a further PRP (4.2) onto the ARTC to monitor dust levels near trains and determine the extent to which coal and freight trains contribute to increased ambient particulate levels.

The data collected by the ARTC through a single trackside monitor from November 2012 to January 2013 has been through multiple series of analysis by both the ARTC consultants and independent peer reviewers which have led to various conclusions about the nature and extent of the particulate profile when loaded and unloaded coal trains, and freight and passenger trains passed by the monitor. This work is discussed in detail in Chapter 2 above.

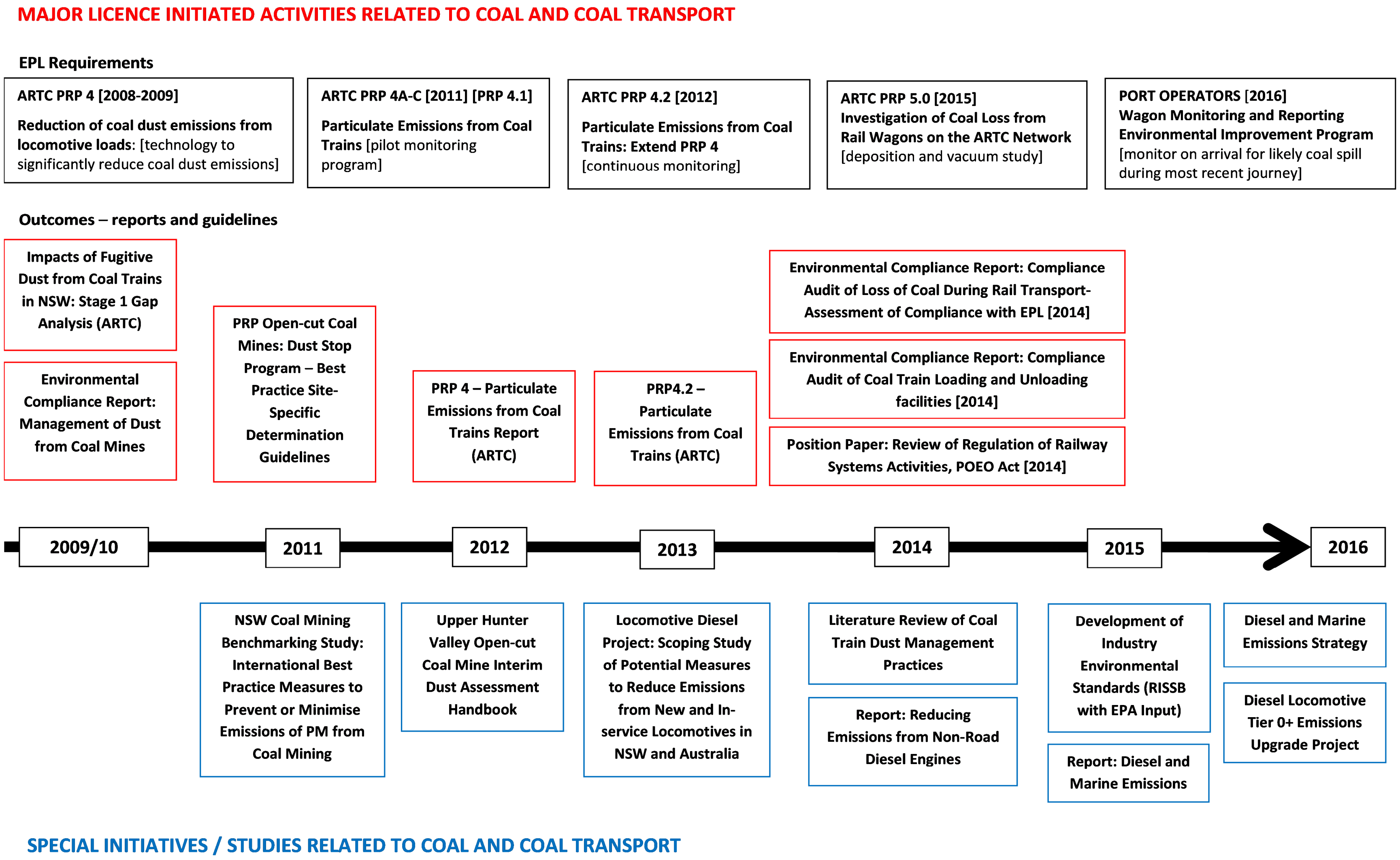
In 2015, further work was required under PRP 5.0 ‘Investigation of Coal Loss from Rail Wagons on the ARTC network’ and included investigation of deposited coal on departure roads and assessment of the efficacy of removing coal from ballast through vacuuming (Figure 8).

In February 2016, all Port Operators were also required to undertake a Wagon Monitoring and Reporting Environmental Improvement program to monitor and report on the condition of coal wagons on arrival to identify the likelihood of coal being spilt into the corridor on the most recent journey. A formal review will be undertaken on the program in September 2016.

3.2.5 Commissioned scientific studies

EPA-commissioned scientific studies have provided some additional insight into the contribution of coal to particulate emissions in the region. These studies include the Upper Hunter Fine Particle Characterisation Study (Hibberd et al., 2013), Lower Hunter Dust Deposition Study (AECOM, 2016) and Lower Hunter Particle Characterisation Study (Hibberd et al., 2016) which are discussed in Chapter 2.

Figure 8: Coal and coal transport focused licence requirements, initiatives and outcomes including reports



3.2.6 Diesel emissions

In the course of consultations, concerns were raised about the contribution of locomotive diesel to particulate levels. This was also identified as a potentially important source in the work undertaken by Ryan when reanalysing Hunter coal train emissions data (Ryan & Wand, 2014).

Increasingly stringent standards for particulate and gaseous emissions from locomotives were introduced from 2000 in the United States and 2004 in the European Union (DieselNet, 2016). Currently Australia has no national standards for exhaust emissions for locomotives, whether new or through upgrades to the existing fleet.

The EPA has undertaken work to assess the feasibility and impact of introducing standards to new and existing locomotives and technologies to retro-fit existing stock. The latter is particularly important in light of the low turnover of the locomotive fleet. This work included commissioning a scoping study and public consultations on potential measures to reduce emissions from locomotives and release of a diesel and marine emissions management strategy (ENVIRON, 2013; NSW EPA, 2014b, 2014c, 2015). The EPA recently released a report of work undertaken with rolling stock operator Pacific National to test the impacts of installing emission upgrade kits on exhaust emissions, fuel efficiency and noise on two Electromotive Diesel (EMD) locomotives using US Tier 0+ emission standards (standards applying to locomotives originally manufactured from 1973) (DieselNet, 2016; US EPA, 2016a). Findings of the post kit-fitting include significant reductions of emissions including particulate matter (weighted results ranging from 59% to 66% g/kWhr), oxides of nitrogen (weighted results ranging from a 30% to 44% g/kWhr reduction), carbon monoxide and total hydrocarbons of up to 70%, but a concurrent increase in carbon dioxide and decrease in fuel efficiency (ABMARC, undated). The report suggests further testing is warranted given the kit manufacturing specifications indicate fuel consumption improvement in the order of 2-5%. The EPA reports that further testing of emissions and fuel consumption using different engine settings is being undertaken, with results anticipated to be released later in 2016 (NSW EPA, 2016a).

3.3 INDUSTRY INITIATIVES TO UNDERSTAND SOURCES AND QUANTITIES OF COAL LOSS AND MANAGE COAL EMISSIONS

A number of studies and initiatives are being undertaken by industry stakeholders across parts of the supply chain to better understand the impacts that coal trains have on air quality and the effectiveness of various management techniques. Some of these efforts are mandated by licence conditions (e.g. PRPs 4, 4.2 and 5.0 discussed in previous section) and others are self-instigated; some are more generic while others are specifically targeted at better understanding single sources.

The industry has made efforts through operating practices to reduce emissions from loading and unloading facilities and while coal is in transit, some as a result of the EPA audit of facilities in 2014. Profiling loads, automatic loading stations and water sprays are a number of procedures in use at some loading facilities to reduce coal loss from wagons while others are deployed to reduce parasitic loads in empty wagons. The coal export terminals are inspecting and reporting any arriving trains that are not properly loaded, as well as managing unloading with water sprays and avoiding coal ploughing to reduce the risks of carry back coal. Wagon doors are frequently inspected and maintained and checked to ensure they are locked closed after unloading.

In terms of monitoring the effectiveness of operating practices and resulting air emissions, the coal mining industry and coal ports (Section 3.2.2) are required to operate networks of monitors as part of their development consents and Environmental Protection Licence conditions. In addition, mining companies also fund the Upper Hunter Air Quality Monitoring Network operated by OEH and are required to make their monitoring data available on their websites.

Work is also being undertaken to examine the relationship between unloading practices and coal loss from empty wagons on departure roads from the port.

The ARTC, in conjunction with stakeholders and the NSW EPA, is investigating coal deposition on rail corridor infrastructure, under the PRP 5.0 Investigation of Coal Loss from Rail Wagons on the ARTC Network. There are two components to this work, a drop sheet study and a vacuuming trial, both discussed in Chapter 2.

Other studies recently undertaken or being considered include two programs of wind tunnel testing to determine potential lift off of coal from the surface of wagons for various NSW coal types and the effectiveness of surface treatments; and an opacity monitoring study to validate the results of the wind tunnel testing and to identify trains that are emitting higher levels of visible dust (NSW Minerals Council, 2016). These are also discussed in Chapter 2.

Port Waratah Coal Services (PWCS) and the Newcastle Coal Infrastructure Group (NCIG) are also investigating the viability of a study to monitor dust emissions from the top of empty wagons. At the time of this report, a literature review had been undertaken and the approach and methodology are under consideration.

Each of these pieces of industry-initiated work will provide insights into the sources and pathways of dust in the coal chain and variability along the rail corridor. They also have value in building a broader body of knowledge that can help inform future studies or management efforts.

3.4 CURRENT AND POTENTIAL DUST MITIGATION STRATEGIES

There is an extensive range of mitigation strategies that can be employed to reduce dust emissions in the coal supply chain.

Some of these are standard operational practices, some are employed to ensure the conditions of EPLs or other legal requirements are met, and some are voluntarily applied by industry operators. Some practices are regarded as of potential application, but are not implemented due to cost and/or lack of knowledge about their efficacy in practical terms.

Practices which are standard in NSW include CCTV, direct observation and wagon door triggers at unloading facilities. Automated loading is being phased in, only one mine currently does not use automated loading.

Other practices, such as covering or veneering, have been proposed as possible additional measures. A summary of the strategies that can be employed is contained in Appendix 4, and are described more extensively elsewhere (Connell Hatch, 2008; Katestone Environmental Pty Ltd, 2014).

The choice of measures or combination of measures at any stage of the coal chain needs to be informed by an understanding of factors such as coal properties, pollutant sources and local climate, as these will have a material bearing on the measures' efficacy. Detailed consideration of safety, relative advantages and disadvantages (including potential unintended consequences) and functionality under NSW conditions will also be required.

As discussed in Chapter 2, coal handling activities (a component of which is the transport within the rail corridor) may unintentionally release coal dust into the air, known as fugitive emissions. These cannot at present be readily measured, but they can be categorised to assist in deciding where to allocate mitigation efforts to have the greatest impact in reducing emissions. In the context of train transport in the coal chain, the five primary areas of interest are:

- asset design/operations/management
- wagon loading practices
- rail transit
- unloading practices
- transfer at the coal terminals (as similar methods could be employed in the transport of coal in the rail corridor).

These areas of interest are briefly outlined below. The Review has included this section to provide an overview of current and potential mitigation strategies. However, until more data are available about the precise amount and distribution of coal dust emissions in the rail corridor, as discussed in Chapter 2, the Review is not able to make any recommendations on specific mitigation techniques.

3.4.1 Asset design/operations/management

Current design techniques include optimising wagon discharge doors to reduce leakage through minimising/sealing gaps, and optimising door release and clearance rate. Regular track maintenance to ensure its integrity, in order to reduce vibrations, would reduce the chance for fugitive emissions.

Potential techniques include retrofitting emission kits to existing locomotives, upgrading locomotives, using a higher quality fuel or re-designing coal wagons.

3.4.2 Wagon loading practices

Current strategies to reduce emissions during loading at the mine and during rail transport include the identification of wagon type and tare (as part of a monitoring process), batch weighing systems to load wagons, telescopic chutes to profile the load, using standardised loading/profiling, compaction of loaded wagon, and scanners/profilers to identify and manage excess load height.

3.4.3 Rail transit

Existing methods for controlling fugitive coal dust emissions from coal wagons during transit include the application of water at the loading point for trips of less than two hours duration or additional application for trips of greater than two hours. The efficacy of this method of dust control is supported in a recent study (Katestone Environmental Pty Ltd, 2012). A literature review in 2014 of coal train dust management practices found that keeping coal moisture content above DEM level was a good coal dust prevention measure (Katestone Environmental Pty Ltd, 2014).

The application of a chemical suppressant (commonly referred to as chemical veneering) has also been investigated. Further mitigation designs could incorporate the application of water or chemical suppressant at a common point at the head of the corridor or prior to entry to major population centres.

The implementation and standardisation of driving practices (acceleration/deceleration etc.) have also been implemented. A mitigation technique that has been suggested and investigated (to varying degrees and for different purposes) includes the full or partial covering of wagons.

Other possibilities include limiting capacity of the corridor (i.e. number of train movements per day) and installing barriers (e.g. walls, trees, etc.) to minimise emissions escaping the corridor.

3.4.4 Unloading practices

Present dust control techniques during unloading include: using automatic door release (kwik-drop and bomb-bay doors); unloading within an enclosed building or shed; monitoring (e.g. CCTV, direct observation) to assure receivers aren't overfilled; using water suppressant during unloading; and ensuring that the bottom doors are properly closed after unloading. Loading and unloading in an enclosed space were reported to be good coal dust preventatives (Katestone Environmental Pty Ltd, 2014).

Potential mitigation strategies include: wagon vibrators to clear residual coal; cleaning empty wagons on exiting terminals (e.g. applying spray, washing, brushing or pressurised air to the outside and/or the inside of wagons); cleaning of wheels; cleaning exit tracks; or installing a dust collection system (e.g. fabric filter). Other potential methods are: changing rail loop design, which could influence the efficiency of the process, minimise coal spillage on the in- and out-track and reduce proximity to the community; and implementing a thorough control system.

3.4.5 Transfer methods at the coal terminal

Existing techniques used during transfer of coal at the terminals could be implemented or appropriated for coal transport in the corridor. Dust and emission mitigation strategies currently used at coal terminals include: the use of conveyor containment chutes and wind shields; re-configuration of stockpiles (e.g. location relative to other activities/residential areas); orientation relative to wind direction; and use of pivoting stackers to avoid the need to use bulldozers or similar to reconfigure stockpiles. Another current method includes the use of continuous meteorological and dust monitoring data to control dust suppression of stockpiles in real time. A more drastic proposed measure includes covering stockpiles or shielding of stockpile (e.g. using walls or wind breaks).

3.5 SUMMARY OF THIS CHAPTER

The EPA is the main regulator ensuring that operators in the coal chain minimise air pollution, including coal dust emissions. It uses an outcomes approach to dust emissions management through its licensing regime. Apart from its regulatory and monitoring role, it has been active in conducting or initiating studies to understand pollution impacts in the coal train corridor, and in encouraging industry to undertake studies to understand coal train impacts.

However, as explained in Chapter 2, there is insufficient knowledge and data about the amount and distribution of coal dust emissions in the rail corridor. To require further specific controls, mitigation strategies or reduced pollution level outcomes as a condition of operating licences, the EPA would benefit from more data on what is actually happening within the rail corridor (in terms of the quantity, source and dispersion pathway of the dust) than is currently available.

Without this information, no cost/benefit analysis and comparison of the economic, environmental or health impacts of the different mitigating measures can be undertaken; and there is no reference point against which the effectiveness of different mitigation approaches can be assessed. The issues associated with obtaining more data are discussed in Chapter 4.

Finding
The Review is unable to make a formal determination on specific mitigation techniques because there is not enough known about the amount and distribution of particulates in the rail corridor and thus no reference point against which to assess mitigation effectiveness. That said, there is a significant body of literature pointing to moisture as a major factor in reducing dust mobilisation at various components of the coal chain (including for coal trains).

4 GETTING THE KNOWLEDGE

In Chapter 3, the Review found that it is unable to make a formal determination on mitigation techniques because there is not enough known about the source, amount and distribution of particulates in the rail corridor and thus no reference point against which to assess mitigation effectiveness.

This chapter discusses the need for further studies, and how that could be done. It discusses methodologies from other linear sources, such as roads and freeways that could be applied to rail corridor studies. Finally, it looks at changes in monitoring technologies and approaches that can be applied in the NSW context.

4.1 NEED FOR FURTHER STUDIES

Following the Review's Initial Report, which posed questions about air quality in or near the rail line, the Review convened a workshop of 11 experts. A list of participants is at Appendix 2.

The lack of a common understanding of the emission rates, sources, variable contribution from different sources (including what proportion is coal) or particle size and how dust is dispersed and deposited was specifically noted by the experts. They also noted that, while studies show some dust 'signatures' with the passage of trains (Higginbotham et al., 2013; Katestone Environmental Pty Ltd, 2013), it remains unclear if the increment of change in dust levels in the corridor and the dispersion of the plume is sufficient to affect health.

The expert workshop canvassed a range of desktop and in-field studies, with options refined through a process of asking what could be done; what is essential to deliver good data on the most pressing questions; and what is the most efficient sequencing approach to any additional work in terms of time, effort and cost.

The workshop noted that some key design elements underpinning further studies needed to include the following:

- while assessing impacts against standards is important, it is also important to consider the consequences to human health of impacts such as increases in particulate exposure, length of exposure, the size of the affected population and scale of increased concentration
- particulate size data are important for characterising the emission sources calculating exposures and health impacts, given it is the respirable fraction that is most important for health
- it is important to understand NSW Health data requirements to ensure that questions in any additional rail corridor studies are appropriately framed and the data generated from them are readily useable, given that health impacts are estimated using associations determined from long term cohort and time series studies
- it is essential to understand, as far as possible, the contribution of different sources of particulates so that if impacts are identified, this information can be used to inform effective mitigation choices.

The workshop proposed a staged approach to gathering the most essential data, working through questions sequentially and using a mix of desktop modelling and in-field studies.

Stage 1 (Part A) of the data-gathering exercise proposed by the expert workshop involves an initial desktop study to develop a risk evaluation framework that relates incremental increases in particulate exposure to health impacts established through large scale epidemiological studies. It involves determining the health endpoints to be used, drawing on available literature, and undertaking mathematical calculations to establish what amount of change (of particulates) would need to be observed in the rail corridor (the 'exposure') that can then be related back to an increased risk to human health (endpoints – the response") e.g. all-cause mortality, mortality or morbidity due to cardiovascular disease etc. The end result will be an evaluation framework including risk ranges as described below.

Stage 1 (Part B) would establish study methods and parameters to gather the relevant data, and apply these to the evaluation framework established from Part A. It involves an in-field study to measure particulate concentrations in the rail corridor (at one or more sites) and compare these with out-of-corridor levels (measured through the ambient monitoring network) to obtain evidence of variation (increase). If observed, the level of increased concentration of particulates would then be assessed as to whether it is statistically significant over the relevant timeframe (e.g. annual average increase). If the change is statistically significant, then this would be assessed against the evaluation framework in Part A.

If Stage 1 Part B shows increased levels of particulates in the rail corridor that are statistically significant and are relevant to the identified health endpoints, then **Stage 2** would be undertaken. This involves an extension of in-field studies by locating a number of monitors at selected locations further out from the rail line to measure the extent of the dust plume from the rail line, thus providing a profile or cross-section of the plume to understand how far it reaches from the track, at what distance the concentrations drops back to background, and other characteristics.

The nearest monitoring site to the corridor perimeter would be determined through further desktop work to understand where the most exposed properties would be (those houses closest to the corridor are likely to be in the order of tens of metres from the track) to understand the upper bound of exposure. The particulate levels measured at this location would also be compared with in-corridor and background levels to determine statistical significance, and then assessed against the evaluation framework.

If the levels here (at this close proximity) didn't demonstrate a statistically significant increase, (being the upper bound worst case scenario) then it would be unlikely that locations further out from the track would be higher. Consideration could then be given to whether or not to progress with the study.

Stage 2 would also include sampling to further explore what particulates people may be exposed to i.e. whether coal or other types of particulates, and the relative contributions of different sources. Consideration of appropriate risk management and mitigation strategies would follow the answers to these questions.

A full summary of the outcomes from the expert workshop, including detailed tables of the infield components for Stages 1 and 2, the Stage 1 (Part A) study design, questions and methods, and the Stage 1 (Part B) key requirements and accounting for in-field factors, is at Appendix 2.

The expert workshop proposals are very dependent on having the right kind of monitors in the right kind of places collecting the right kinds of data. This issue is discussed below.

4.2 LINEAR SOURCE DATA MONITORING METHODOLOGIES

Few studies have specifically focused on emissions originating from the rail corridor. However, numerous studies have been conducted on the monitoring of air quality around roads and, in particular, high-load roads such as freeways. Roads and rail corridors, although functionally different, act in similar manner as a linear source of airborne particulate matter. Therefore, similar monitoring methodologies could be adapted for rail corridor studies from road emission studies.

A study by Karner, Eisinger, and Niemeier (2010) reviewed and synthesised methodologies and results from over 40 roadside monitoring studies. It stated that:

- the most frequently applied method to determine dispersion gradients was to place monitoring equipment, at varying distances, along a vector approximately perpendicular to the source (road)
- the studies typically utilised prevailing wind patterns to orientate monitors in an upwind/downwind configuration from the road, in order to establish a baseline measurement for comparison with the downwind measurements. This was typically in conjunction with collocated meteorological equipment at the monitoring sites to confirm wind direction (Hitchins, Morawska, Wolff, & Gilbert, 2000).

Furthermore, a study by Baldauf, Watkins, Heist, Bailey, Rowley, and Shores (2009) examined network design and identified key factors that need to be considered in the collection and interpretation of near-road air quality data. Many of these factors are applicable to or adaptable to rail corridor studies, including:

- the parameters surrounding traffic, such as the numbers, type and speeds of vehicles
- meteorological measurements, such as wind speed and direction, temperature, relative humidity and atmospheric stability
- monitors appropriate to the variable being measured. For PM_{10} and $PM_{2.5}$, the study indicates a combination of 24-hour sampling (mass measurement via filter-based gravimetric analysis) and continuous PM sampling, as each method has limitations: for example, diurnal variation is missed in the 24-hour sampling whilst some continuous PM sampling monitors use an optical measurement that reduces its accuracy for determining the quantity of smaller particles
- location of monitors relative to structures, vegetation or topographical features that may impact the dispersion of airborne particles
- location of monitors relative to the linear source (road) can influence the actual particle concentration due to numerous variables in that environment, with many studies controlling this via implementing multiple monitoring stations at varying distances from the source.

In the Review's discussion with a New Zealand air quality expert who advises various NSW government agencies, Dr Ian Longley from NIWA, the Review noted the contrast between Australia's approach to measuring air quality and the New Zealand one. In New Zealand the focus is on monitoring conditions near sources or sites that are identified as having peak levels. This approach of monitoring at peak sites is used for both their ambient measurements, as well as their approach for measuring the impact of specific sources such as road corridors.

In NSW, source monitoring is undertaken for some activities subject to an EPL or development approval for example storing, loading or handling of coal.

By contrast, in New Zealand this approach of monitoring specific sources is undertaken more widely (not necessarily associated with licensing). Monitoring campaigns are undertaken that characterise the conditions for people who live close to sources, including linear sources such as roads as described above.

Combining and adapting these approaches to other locations or activities in NSW would allow more focus to be brought to the questions of what contribution sources and composition of particulate emissions, and thus what is the impact.

4.3 DATA MONITORING TECHNOLOGIES

Two background papers (Keywood & Selleck, 2016; Eggleton, 2016) were commissioned for the Review to provide an overview of current and future advances in sampling, monitoring and measuring technologies for air emissions, with particular reference to how this would apply to emissions from the rail corridor. The background papers are available at http://www.chiefscientist.nsw.gov.au/reports/review-of-rail-coal-dust-emissions.

4.3.1 Current technologies and what they measure

A range of technologies currently exist to measure and monitor particulate matter and other gaseous pollutants. They use a variety of sampling methods to measure specific parameters about the pollutant of interest, which include: particle mass concentration, size and particle number distribution, optical properties like absorption, and chemical composition (Keywood & Selleck, 2016). These properties can be used directly for real-time reporting or the data on these properties can inform dispersion models. Measuring the chemical composition of a particle may also provide insight into the source of the pollutant, whether from coal dust from a train, a wood burning fire, motor vehicles, etc.

Drawing on the commissioned papers, Appendix 5 summarises technologies currently available to measure emissions with some of their known advantages and disadvantages. Whilst each of these technologies may be appropriate for sampling and answering specific emission questions, both papers conclude that there is no single monitor currently available that will fully address the questions posed in this Review.

4.3.2 Quality of data

All of the monitors outlined in Appendix 5 can provide meaningful data. However, the data accuracy is reliant on understanding that all the monitors have limitations, are fit-for-purpose for specific sets of measurements, and have inherent uncertainties in their operation and measurement capabilities. Eggleton proposes two types of uncertainties: type A, which is statistical uncertainty, and type B, which is systematic uncertainty (Eggleton, 2016). There are multiple ways to reduce the influence of these factors, including operating equipment within Australian Standards (if applicable); calibration of equipment; and a robust study design (which would use an appropriate spatial and temporal resolution).

Australian Standards exist for the measurement of particle concentrations (including TSP, PM_{10} and $PM_{2.5}$) using low and high volume sampler gravimetric methods, dichotomous sampler gravimetric methods, and continuous direct mass methods using TEOM, BAM and light scattering nephelometers (Keywood & Selleck, 2016). When monitors are used in accordance with these standards, they indicate a benchmark of quality in the data due to the correct operation of the equipment, and can reduce some of the in-built type B uncertainties associated with these devices. The Review notes that instruments which meet NEPM standards, such as the TEOM (Tapered Element Oscillating Microbalance) and BAM (Beta Attenuation Monitor), tend to be expensive.

The accuracy of most of the particle instruments is determined by their calibration and the time required for a sufficient mass of material to be accumulated for measurement (Eggleton, 2016). For example, in the context of this Review, a low-cost commercial device may be factory calibrated against ‘standard’ dust samples rather than coal particles (and, more specifically, coal samples from the region); leading to an unknown level of uncertainty (type B uncertainty) and accuracy when measuring for absolute quantities. However, it should be noted that there can still be value in using the data generated by this approach as a comparative measure (i.e. to compare one train to another or one site to another).

The quality of data is dependent on the spatial and temporal resolution required. A monitoring system to measure the air emissions in the rail corridor will need both high spatial and temporal resolution to be able to measure a large enough area to capture a plume and to provide information about spikes related to passing trains (Eggleton, 2016). For example, the methods and technology used for ambient measurements in the Upper and Lower Hunter Network generally have a lower temporal resolution, and that is due to their intended purpose of measuring against 24-hour and annual ambient NEPM standards. A robust study design, using monitors that have an appropriate temporal resolution and are placed over an appropriate spatial scale in order to capture the right data, would reduce issues of type A uncertainty.

4.3.3 Application of technological advances

There have been significant sequential steps in the advancements of air quality monitoring technologies and methods. In particular, there is a new category of easily networked, low cost, smartphone-compatible monitoring tools that are being deployed in citizen science networks (Eggleton, 2016). The indication from the two commissioned papers and from the workshop is that no single technology or method, on its own, will quantify emissions from the rail corridor but various combinations could. However, as monitoring technology becomes cheaper, increasingly mobile and easier to deploy successfully, this will lead to new methodologies and approaches to monitoring air quality at an ambient point source or, in the case of the rail corridor, at a linear source level. Dr Longley suggested that these newer technologies alone may not achieve NEPM standards in the short to medium term, and data from them could not be compared directly with data from instruments that do meet the standard. However, this would not preclude their use for a number of comparative purposes, e.g. today with yesterday or one location with another. Integration of current, new and emerging technologies may be an integral part of a study design, using a combination of commercially available instrumentation with some specialised and state of the art components (Eggleton, 2016; Keywood & Selleck, 2016). The monitors could be point monitors, open path monitors or mobile monitors or a combination of these, feeding a spatio-temporal model of the local site to measure the dynamics of the concentration of particulates.

Already there are international moves to use networks of low-cost sensors, combined with advanced data analysis, to measure the size distribution, chemical composition and concentration of particles and gaseous pollutants as the source (e.g. coal train) passes, and follow its dispersal over time and distance. This method of using a network of sensors has been successfully employed at locations including London (Eggleton, 2016) and for a previous study in Boston (Gryparis, Coull, Schwartz, & Suh, 2007). Using a dense network of them along the rail corridor, with performance characteristics rigorously quantified and combined with data fusion analysis techniques and statistical analysis could address the claimed unsuitability of low-cost sensors as a stand-alone monitor for particle concentrations and can provide robust information on particle concentrations (Keywood & Selleck, 2016).

In relation to measuring localised pollution levels such as those associated with specific point or linear sources, Dr Longley told the Review that development of a long-term adaptive monitoring system was at least as important as having sets of individual sensors (no matter how high the quality of the sensor). Ensuring sensors are part of a standardised and controlled system rather than treated as individual data collectors is important. In essence, the system would be managed adaptively, employing machine learning and data fusion techniques, and thus providing a real-time summary of pollutant profiles for that network.

In short, there continue to be challenges in terms of the ability to validate the results from various sampling methods and monitors, but rigorous study design can help minimise these issues and address concerns from previous studies based on single monitor and/or location methodologies.

4.4 SUMMARY

A workshop of experts convened by the Review has proposed a staged approach to gathering the most essential data required to understand coal dust impacts in the rail corridor, working through questions sequentially and using a mix of desktop modelling and in-field studies. This could be used as the basis for a pilot study.

In implementing such a study and future, related studies, methodologies can be adapted from studies done on other linear sources, such as roads and freeways. Lessons can also be learned from approaches taken in New Zealand and under NSW EPLs.

Monitoring technology is rapidly advancing and becoming cheaper. And very rapid advances are being made in the data analytics domain especially in data fusion from multiple, often heterogeneous sources. A combination of new technologies with existing standards-rated instruments has great potential for application in the rail corridor immediately and, with innovative design, many new sensing technologies should be able to replace (or at least enhance the results from) existing technologies and do this at significantly lower cost and higher data integrity.

Ideally banks of these new, cheaper sensors will give us a real-time picture of the air quality around pollutant sources (including along the rail corridor) so that anyone can access this data which ideally would be available both in raw form and in convenient graphical representations (in the same manner that a range of sensor data is made available on the very popular Bureau of Meteorology website).

Recommendation 1
It is recommended that NSW adopt a dual approach to ensuring air quality through:

i. the current focus on background ambient air quality by way of a well-structured network of standardised (including NEPM) monitors
ii. a systematic focus on spatial and temporal distribution of air pollutants attributable to specific sources, with an initial focus on particulates from local, though possibly moving, sources (e.g. trains) in the coal chain. This will require banks of dedicated monitors, that form separate networks to the NEPM network, the data from which will allow real-time monitoring and will provide input for new specific local air quality models of pollution from source to where air quality is at background levels.

The data for both foci must be of high quality and publicly available.

Recommendation 2
It is recommended that a pilot study be designed and implemented for the rail corridor that would capture more detailed information and data on whether there is a statistically significant increase in particulate levels within the corridor, how far out from the corridor the particulate profile extends, and whether this would result in an unacceptable increased health risk for people living in the vicinity of the corridor. In order to allow for worst cases, it is suggested that an initial analysis of potential hotspots be undertaken to inform decisions about the placement of the banks of monitors for the pilot.

This pilot study would have a range of outcomes. Importantly, it would clarify the situation for the rail corridor and vicinity on whether there is an unacceptable health concern. Secondly, through utilisation of techniques that identify particulate components, it would clarify the source or pathway of the particulate dispersion and thus inform the choice of mitigation approaches to have the greatest impact in reducing dust levels from the corridor. Thirdly, by employing standard NEPM-monitors in addition to banks of smaller, cheaper sensors, it will help establish and refine methodologies for the deployment of integrated networks of small cheap sensors and models, where a process of comparing and standardising needs to occur between the results from NEPM monitors and the smaller cheaper monitors.

The Review consulted air quality and sensor experts on the likely cost of such a pilot study. It is estimated that it is unlikely to cost more than $250,000 and could cost considerably less.

Recommendation 3
It is recommended that following the pilot study, a process of monitoring pollutant sources at close range be rolled out. This will involve the design, development and deployment of cost-effective monitors for measuring air quality near pollutant sources, and the development of models from the data acquired.

Recommendation 4
It is recommended that all relevant data from industry and government air quality monitors and the associated models be deposited in the NSW Environmental Data Portal and be available to the community (in raw and processed, graphical form) in line with open data principles.

Recommendation 5
It is recommended that rail operator ARTC and all coal producers, coal handlers, coal transporters and companies involved in the coal chain keep all their current mitigation strategies in place (without precluding their further augmentation) until characterisation of the air pollutant profile around the rail corridor is available.

5 CONCLUSIONS AND FINDING

5.1 CONCLUSIONS

Coal dust and emissions in and near the rail corridor have been the subject of expressed community concern for some years. The Review has concluded that while knowledge of ambient air quality is good, gaps remain in our knowledge about air quality in and near the corridor itself.

A number of initiatives have progressed during the course of this Review that will make important contributions to our understanding of air quality issues in and near the rail corridor. We know more about monitoring technologies which may help inform study design choices and instrumentation for sampling and monitoring. The Lower Hunter Dust Deposition and Particle Characterisation studies will improve understanding of ambient air quality and contributing pollution sources. Industry in NSW has been undertaking or considering a range of studies, some self-instigated and some mandated by licence conditions, better to characterise the sources and quantum of coal dust and emissions from trains. It is important that we bring together these different pieces of the puzzle as findings and results emerge.

Notable to the Review was the strength of networks and working relationships that were harnessed to understand issues and trial solutions better, including those across industry and between government agencies and major research institutions. Should Government choose to accept the recommendations in this report, it would be prudent to capitalise on these and bring stakeholders together with the experts to ensure all study efforts are aligned and all research work robust, thereby optimising both learning and investment.

A question that can be anticipated from community members is 'what happens if the proposed pilot study proceeds but a measurable difference is not observed, or the observed difference is small – does this mean nothing needs to be done?' By world standards, Australia has stringent air quality standards for particulates. However, there is currently no evidence of a threshold below which exposure to particulate matter does not cause any health effects. Therefore, efforts to reduce the levels of particulate matter from coal trains can have positive health outcomes, but should be selected to maximise positive and minimise negative effects (e.g. reductions in the quantity of coal per wagon would result in a greater number of wagon or train movements).

The nature of the contributing sources of dust and emissions and the relative contribution of coal dust may vary along the coal supply chain as may the nature and extent of impacts. Any future prevention or mitigation strategies applied to the rail corridor should be informed by a coherent research program to understand better issues and impacts on a localised level as well as initiatives already in place. Without pre-empting any results, it may be that some strategies should be applied globally across the coal supply chain while others may be more sensibly targeted and applied on a selective basis for maximum impact, while in all cases minimising unintended negative consequences.

5.2 FINDING AND RECOMMENDATIONS

Finding

The Review is unable to make a formal determination on specific mitigation techniques because there is not enough known about the amount and distribution of particulates in the rail corridor and thus no reference point against which to assess mitigation effectiveness. That said, there is a significant body of literature pointing to moisture as a major factor in reducing dust mobilisation at various components of the coal chain (including for coal trains).

Recommendations

Recommendation 1

It is recommended that NSW adopt a dual approach to ensuring air quality through:

i. the current focus on background ambient air quality by way of a well-structured network of standardised (including NEPM) monitors
ii. a systematic focus on spatial and temporal distribution of air pollutants attributable to specific sources, with an initial focus on particulates from local, though possibly moving, sources (e.g. trains) in the coal chain. This will require banks of dedicated monitors, that form separate networks to the NEPM network, the data from which will allow real-time monitoring and will provide input for new specific local air quality models of pollution from source to where air quality is at background levels.

The data for both foci must be of high quality and publicly available.

Recommendation 2

It is recommended that a pilot study be designed and implemented for the rail corridor that would capture more detailed information and data on whether there is a statistically significant increase in particulate levels within the corridor, how far out from the corridor the particulate profile extends, and whether this would result in an unacceptable increased health risk for people living in the vicinity of the corridor. In order to allow for worst cases, it is suggested that an initial analysis of potential hotspots be undertaken to inform decisions about the placement of the banks of monitors for the pilot.

Recommendation 3

It is recommended that following the pilot study, a process of monitoring pollutant sources at close range be rolled out. This will involve the design, development and deployment of cost-effective monitors for measuring air quality near pollutant sources, and the development of models from the data acquired.

Recommendation 4

It is recommended that all relevant data from industry and government air quality monitors and the associated models be deposited in the NSW Environmental Data Portal and be available to the community (in raw and processed, graphical form) in line with open data principles.

Recommendation 5

It is recommended that rail operator ARTC and all coal producers, coal handlers, coal transporters and companies involved in the coal chain keep all their current mitigation strategies in place (without precluding their further augmentation) until characterisation of the air pollutant profile around the rail corridor is available.

6 REFERENCES

ABMARC. (undated). Diesel Locomotive Emissions Upgrade Kit Demonstration Project - Fuel Efficiency, Emissions & Noise Testing. Victoria.

ACARP. (2012). Managing dust emissions from mine to port (abstract of report by John Planner, Introspec Consulting). *ACARP Matters*. http://www.acarp.com.au/Media/ACARPMatters_24_Dust.pdf

ACARP. (2015). Reduction of Carry-back and Coal Spillage in Rail Transport (abstract of report published by Einicke, G, Hargrave, C, Thomspon, J, Plunkett, C, Paterson, S (2008) for Australian Coal Research Ltd.). http://www.acarp.com.au/abstracts.aspx?repId=C15071

ACTAQ. (2014a). *Initial Report on Tunnel Air Quality*. Advisory Committee on Tunnel Air Quality.

ACTAQ. (2014b). *TP03: Health Effects of Traffic-Related Air Pollution*. Advisory Committee on Tunnel Air Quality.

AECOM. (2016). Lower Hunter Dust Deposition Study Final Report.

ARTC. (2016). *ARTC Coal Deposition and Removal Works - Summary*.

Aurecon Hatch. (2009). Coal Leakage from Kwik-Drop Doors Coal Loss Management Project Queensland: Prepared for Queensland Rail Limited (now Aurizon).

Australian Government. (2015). National Clean Air Agreement.

Australian Rail Track Corporation Ltd. (2009). 2009-2018 Hunter Valley Corridor Capacity Strategy Consultation Document

Australian Rail Track Corporation Ltd. (2015). 2015-2024 Hunter Valley Corridor Capacity Strategy.

Ayling, B, Rose, P, Petty, S, Zemach, E, & Drakos, P. (2012). QEMSCAN® (Quantitative Evaluation of Minerals by Scanning Electron Microscopy): capability and application to fracture characterization in geothermal systems *PROCEEDINGS,* (Vol. Thirty-Seventh Workshop on Geothermal Reservoir Engineering): Stanford University.

Baldauf, R, Watkins, N, Heist, D, Bailey, C, Rowley, P, & Shores, R. (2009). Near-road air quality monitoring: Factors affecting network design and interpretation of data. *Air Quality, Atmosphere & Health, 2*(1), 1-9. doi: 10.1007/s11869-009-0028-0

Barnett, A.G, Williams, G.M, Schwartz, J, Best, T.L, Neller, A.H, Petroeschevsky, A.L, & Simpson, R.W. (2006). The effects of air pollution on hospitalizations for cardiovascular disease in elderly people in Australian and New Zealand cities. *Environ Health Perspect, 114*(7), 1018-1023.

Begg, S, Vos, T , Barker, B, Stevenson, C, Stanley, L , & Lopez, AD. (2007). The burden of disease and injury in Australia 2003. PHE 82. Canberra: Australian Institute of Health and Welfare.

Bernstein, J. A, Alexis, N, Barnes, C, Bernstein, I. L, Bernstein, J. A, Nel, A., Peden, D., Diaz-Sanchez, D., Tarlo, S. M., & Williams, P. B. (2004). Health effects of air pollution. *J Allergy Clin Immunol, 114*(5), 1116-1123. doi: 10.1016/j.jaci.2004.08.030

BNSF. (2010). Summary of BNSF/UP Super Trial 2010. www.bnsf.com/customers/pdf/coal-super-trial.pdf

Brook, RD, Rajagopalan, S, Pope, CA, III, Brook, JR, Bhatnagar, A, Diez-Roux, AV, Holguin, F, Hong, Y, Luepker, RV, Mittleman, MA, Peters, A, et al. (2010). Particulate matter air pollution and cardiovascular disease: An update to the scientific statement from the American Heart Association. *Circulation, 121*(21), 2331-2378. doi: 10.1161/CIR.0b013e3181dbece1

Cohen, DD, Crawford, J, Stelcer, E, & Atanacio, AJ. (2014). Revealing the sources of Sydney's air pollution. Retrieved 25 November 2015, from http://www.ansto.gov.au/AboutANSTO/MediaCentre/News/ACS049674

Connell Hatch. (2008). Final Report - Environmental Evaluation of Fugitive Coal Dust Emissions from Coal Trains Goonyella, Blackwater, and Moura Coal Rail Systems. Prepared by Connell Hatch (now Aurecon Hatch): Queensland Rail Limited.

Crouse, D. L., Peters, P. A., van Donkelaar, A., Goldberg, M. S., Villeneuve, P. J., Brion, O., Khan, S., Atari, D. O., Jerrett, M., Pope, C. A., Brauer, M., et al. (2012). Risk of nonaccidental and cardiovascular mortality in relation to long-term exposure to low concentrations of fine particulate matter: a Canadian national-level cohort study. *Environ Health Perspect, 120*(5), 708-714. doi: 10.1289/ehp.1104049

Dalton, CB, Durrheim, DN, Marks, G, & Pope, CA, III. (2014). Investigating the health impacts of particulates associated with coal mining in the Hunter Valley. *Air Quality and Climate Change, 48*(6), 39-43.

Department of Science, Information Technology and Innovation. (2016). Air quality bulletin South East Queensland February 2016: Queensland Government.

DieselNet. (2016). *Engine and emission technology online.* Retrieved 8 March 2016, 2016, from https://www.dieselnet.com/

DSITIA. (2012). *Tennyson Dust Monitoring Investigation - September to October 2012*. Queensland: Department of Science, Information Technology, Innovation and the Arts. Retrieved from www.ehp.qld.gov.au/air/pdf/tennyson-dust-report.pdf.

DSITIA. (2013). *Western - Metropolitan Rail Systems Coal Dust Monitoring Program - Final Report*. Queensland: Department of Science, Information Technology, Innovation and the Arts. Retrieved from www.ehp.qld.gov.au/management/coal-dust/pdf/rail-coal-dust-final-report.pdf.

Eggleton, B. (2016). Information paper on sensor and monitoring technologies.

EMGA Mitchell McLennan. (2012). T4 Project: environmental assessment. NSW: Prepared for Port Waratah Coal Services.

ENVIRON. (2012a). Air Quality Assessment for the Terminal 4 Project. Prepared by ENVIRON Australia Pty Ltd, for Port Waratah Coal Services Ltd.

ENVIRON. (2012b). Pollution Reduction Program (PRP) 4 - Particulate Emissions from Coal Trains: Prepared by ENVIRON Australia Pty Ltd for Australian Rail Track Corporation.

ENVIRON. (2013). Locomotive emissions project: Scoping study of potential measures to reduce emissions from new and in-service locomotives in NSW and Australia. Environ Australia Pty Ltd.: Prepared for the NSW Environment Protection Authority.

Environment and Climate Change Canada. (2016). International Comparison of Urban Air Quality.

Farzaneh, M, Lee, J, Villa, J, & Zietsman, J. (2011). Corridor-Level Air Quality Analysis of Freight Movement. *Transportation Research Record: Journal of the Transportation Research Board, 2233*, 19-26. doi: 10.3141/2233-03

Ferreira, AD, & Vaz, PA. (2004). Wind tunnel study of coal dust release from train wagons. *Journal of Wind Engineering and Industrial Aerodynamics, 92*(7–8), 565-577. doi: 10.1016/j.jweia.2004.03.003

Ferreira, AD, Viegas, DX, & Sousa, ACM. (2003). Full-scale measurements for evaluation of coal dust release from train wagons with two different shelter covers. *Journal of Wind Engineering and Industrial Aerodynamics, 91*(10), 1271-1283. doi: 10.1016/S0167-6105(03)00077-1

Fuller, G, Baker, T, Tremper, A, Green, D, Font, A, Priestman, M, Carslaw, D, Dajnak, D, & Beevers, S. (2014). Air pollution emissions from diesel trains in London: Environmental Research Group, King's College London.

General Purpose Standing Committee No. 5. (2015). *The performance of the NSW Environment Protection Authority.* New South Wales Parliament: Legislative Council. Retrieved from http://www.parliament.nsw.gov.au/prod/parlment/committee.nsf/0/743BDB8875807D85CA257CFC002142D1.

Golder Associates Pty Ltd. (2013). *Exposure Assessment and Risk Characterisation to Inform Recommendations for Updating Ambient Air Quality Standards for PM2.5,*

PM10, O3, NO2, SO2. Prepared for National Environmental Protection Council Service Corporation.
Gryparis, A, Coull, B.A, Schwartz, J, & Suh, H.H. (2007). Semiparametric latent variable regression models for spatiotemporal modelling of mobile source particles in the greater Boston area. *Journal of the Royal Statistical Society: Series C (Applied Statistics), 56*(2), 183-209. doi: 10.1111/j.1467-9876.2007.00573.x
Gysel, Martin, Mensah, A. A., Corbin, J. C., Keller, A., Kim, J., Petzold, A., & Sierau, B. (2012). The single particle soot photometer fails to reliably detect PALAS soot nanoparticles. *Atmospheric Measurement Techniques, 5*(12), 3099-3107. doi: 10.5194/amt-5-3099-2012
Hand, R, D, Pingkuan, Servin, A, Hunsaker, L, & Suer, C. (2004). *Roseville Rail Year Study*. California Environmental Protection Agency Air Resources Board. Retrieved from http://www.arb.ca.gov/diesel/documents/rrstudy/rrstudy101404.pdf.
Harrison, R.M, Beddows, D.C.S, Jones, A.M, Calvo, A, Alves, C, & Pio, C. (2013). An evaluation of some issues regarding the use of aethalometers to measure woodsmoke concentrations. *Atmospheric Environment, 80*, 540-548.
Health Effects Institute Panel. (2010). Traffic-related air pollution: a critical review of the literature on emissions, exposure, and health effects.
Hibberd, M.F, Keywood, M.D, Cohen, D.D, Stelcer, E, Scorgie, Y, & Chang, L. (2016). Lower Hunter Particle Characterisation Study, Final Report.
Hibberd, M.F, Selleck, P.W, Keywood, M.D, Cohen, D.D, Stelcer, E, & Atanacio, A.J. (2013). Upper Hunter Particle Characterisation Study: Final Report. CSIRO: Prepared for NSW Office of Environment and Heritage and NSW Department of Health.
Higginbotham, N , Ewald, B, Mozeley, F, & Whelan, J. (2013). Coal Train Pollution Signature Study. Coal Terminal Action Group Dust and Health Committee: Coal Terminal Action Group.
Hime, N. (2015). *The health impacts of particulate matter in diesel exhaust emissions (with a focus on cancer)*. Presentation for Woolcock Institute of Medical Research.
Hime, N, Cowie, C, & Marks, G. (2015). *Review of the health impacts of emissions sources, types and levels of particulate matter air pollution in ambient air in NSW*. Produced by the Woolcock Institute of Medical Research, Centre for Air Quality and Health Research and Evaluation (CAR) for the NSW Environment Protection Authority and NSW Ministry of Health, Environmental Health Branch.
Hitchins, J, Morawska, L, Wolff, R, & Gilbert, D. (2000). Concentrations of submicrometre particles from vehicle emissions near a major road - lines that divide. *Atmospheric Environment, 34*(1), 51-59. doi: 10.1016/S1352-2310(99)00304-0
Howe, G.R, Fraser, D., Lindsay, J, Presnal, B, & Yu, S.Z. (1983). Cancer mortality (1965-77) in relation to diesel fume and coal exposure in a cohort of retired railway workers. *J Natl Cancer Inst, 70*(6), 1015-1019.
Hricko, A, Rowland, G, Eckel, S, Logan, A, Taher, M, & Wilson, J. (2014). Global Trade, Local Impacts: Lessons from California on Health Impacts and Environmental Justice Concerns for Residents Living near Freight Rail Yards. *International Journal of Environmental Research and Public Health, 11*(2), 1914. doi: 10.3390/ijerph110201914
Hyvarinen, A, Vakkari, V, Laakso, L, Hooda, R.K, Sharma, V.P, Panwar, T.S, Beukes, J.P, Van Zyl, P.G, Josipovic, M, Garland, R.M, Andreae, M.O, et al. (2013). Correction for a measurement artifact of the Multi-Angle Absorption Photometer (MAAP) at high black carbon mass concentration levels. *Atmospheric Measurement Techniques, 6*, 81-90.
IARC. (2012). IARC: Diesel engine exhaust carcinogenic. *Press release No. 213*, 4.
Institute of Air Quality Management. (2012). Guidance on Air Quality Monitoring in the Vicinity of Demolition and Construction Sites.
Jaffe, D, Hof, G, Malashanka, S, Putz, J, Thayer, J, Fry, JL, Ayres, B, & Pierce, JR. (2014). Diesel particulate matter emission factors and air quality implications from in–service

rail in Washington State, USA *Atmospheric Pollution Research, 5*, 344-351. doi: 10.5094/APR.2014.040

Jaffe, D, Putz, J, Hof, G, Hof, G, Hee, J, Lommers-Johnson, D, Gabela, F, Fry, JL, Ayres, B, Kelp, M, & Minsk, M. (2015). Diesel particulate matter and coal dust from trains in the Columbia River Gorge, Washington State, USA. *Atmospheric Pollution Research*. doi: 10.1016/j.apr.2015.04.004

Johnson, G.R, Lau, E.R, Thomas, V, Juwono, A.M, Kitchen, B, & Morawska, L. (2013). Remote measurement of diesel locomotive emission factors and particle size distributions. *Atmospheric Environment, 81*, 148-157. doi: 10.1016/j.atmosenv.2013.09.019

Joint WHO/Convention Task Force on the Health Aspects of Air Pollution. (2006). Health risks of particulate matter from long-range transboundary air pollution. Denmark: European Centre for Environment and Health Bonn Office.

Kane, M. (2015). Health Hazard in our suburbs: Particulate pollution along the South-East Queensland coal dust corridor. Queensland: Prepared for Clean Air Queensland.

Karner, AA, Eisinger, DS, & Niemeier, DA. (2010). Near-Roadway Air Quality: Synthesizing the Findings from Real-World Data. *Environmental Science & Technology, 44*(14), 5334-5344. doi: 10.1021/es100008x

Katestone Environmental Pty Ltd. (2012). Duralie Extension Project, Study of Dust Emissions from Rail Transport. Queensland: Prepared for Duralie Coal Pty Ltd.

Katestone Environmental Pty Ltd. (2013). Pollution Reduction Program 4.2 Particulate Emissions from Coal Trains. Queensland: Prepared for Australian Rail Track Corporation Pty Ltd.

Katestone Environmental Pty Ltd. (2014). *Literature Review of Coal Train Dust Management Practices*. Prepared for NSW Environment Protection Authority. Retrieved from http://www.epa.nsw.gov.au/esdsmoky/coaltraindust-litreview.htm.

Katsouyanni, K, Touloumi, G, Samoli, E, Gryparis, A, Le Tertre, A, Monopolis, Y, Rossi, G, Zmirou, D, Ballester, F, Boumghar, A, Anderson, HR, et al. (2001). Confounding and Effect Modification in the Short-Term Effects of Ambient Particles on Total Mortality: Results from 29 European Cities within the APHEA2 Project. *Epidemiology, 12*(5), 521-531. doi: 10.1097/00001648-200109000-00011

Keywood, M, & Selleck, P. (2016). Advances in technologies for sampling, measuring and monitoring coal dust and related emissions along the rail corridor.

Kheirbek, I, Johnson, S, Ito, K, Anan, K, Matte, T, Kass, D, Eisl, H, Gorczynski, J, Markowitz, & Ross, Z. (2015). The New York City Community Air Survey: Neighborhood Air Quality 2008-2013. New York

Kunzli, N, Perez, L, & Rapp, R. (2010). *Air Quality and Health*. Prepared for the European Respiratory Society.

Lane, K. J, Levy, J. I, Scammell, M. K, Patton, A. P, Durant, J. L, Mwamburi, M, Zamore, W, & Brugge, D. (2015). Effect of time-activity adjustment on exposure assessment for traffic-related ultrafine particles. *J Expo Sci Environ Epidemiol, 25*(5), 506-516. doi: 10.1038/jes.2015.11

Lewis, TR, Green, FHY, Moorman, WJ, Burg, JR, & Lynch, DW. (1989). A chronic inhalation study of diesel engine emissions and coal dust, alone and combined. *International Journal of Toxicology, 8*(2), 345-375. doi: 10.3109/10915818909019560

Lim, SS, Vos, T, Flaxman, A, Danaei, G, Shibuya, K, Adair-Rohani, H, Amann, M, Andersen, HR, Andrews, KG, Aryee, M, & Memish, ZA. (2012). A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet, 380*(9859), 2224-2260. doi: 10.1016/s0140-6736(12)61766-8

Longley, I, Kingham, S, Dirks, K, Somervell, E, Pattinson, W, & Elangasinghe, A. (2013). Detailed observations and validated modelling of the impact of traffic on the air quality of roadside communities *NZ Transport Agency research report 516*. New Zealand.

Longley, I, Somervell, E, & Gray, S. (2015). Roadside increments in PM10, NOx and NO2 concentrations observed over 2 months at a major highway in New Zealand. *Air Quality, Atmosphere & Health, 8*(6), 591-602. doi: 10.1007/s11869-014-0305-4
Loomis, D, Grosse, Y, Lauby-Secretan, B, El Ghissassi, F, Bouvard, V, & Tallaa, L. (2013). IARC evaluation of the carcinogenicity of outdoor air pollution. *The Lancet Oncology, 14*(13), 1262-1263. doi: 10.1684/ers.2014.0715
Malm, W.C. (1999). *Introduction to visibility* (Vol. 40): Cooperative Institute for Research in the Atmosphere, NPS Visibility Program, Colorado State University.
Merritt, TD, Cretikos, MA, Smith, W, & Durrheim, DN. (2013). The health of the Hunter Valley communities in proximity to coal mining and power generation, general practice data, 1998-2010. *NSW Public Health Bulletin, 24*(2), 57-104.
Morawska, L, & Moore, MR. (2004). *Health Impacts of Ultrafine Particles: Health Impacts of Ultrafine Particles*. Prepared for Department of the Environment and Heritage.
Morawska, L, Vishvakarman, D, Mengersen, K, & Thomas, S. (2002). Spatial variation of airborne pollutant concentrations in Brisbane, Australia and its potential impact on population exposure assessment. *Atmospheric Environment, 36*, 3545-3555.
NSW Environment Protection Authority. (2016). Newcastle Local Air Quality Monitoring Network and Upper Hunter Air Quality Monitoring Network maps. Retrieved 28 March 2016, from http://www.environment.nsw.gov.au/aqms/newcastlelocalmap.htm and http://www.environment.nsw.gov.au/aqms/uhunteraqmap.htm
NSW EPA. (2014a). *Environment compliance report: Compliance audit of coal train loading and unloading facilities*. NSW Environment Protection Authority. Retrieved from http://www.epa.nsw.gov.au/publications/licensing/140871-comp-audit-coal-train.htm.
NSW EPA. (2014b). *Review of regulation of 'railway systems activities' under the Protection of the Environment Operations Act 1977: Position paper*. NSW Environment Protection Authority. Retrieved from http://www.epa.nsw.gov.au/licensing/railindustry.htm.
NSW EPA. (2014c). *Summary of stakeholder comments and EPA responses on the Locomotive Emissions Project: Scoping study of potential measures to reduce emissions from new and in-service locomotives in NSW and Australia*. Prepared by the NSW Environmental Protection Authority.
NSW EPA. (2015). *Diesel and marine emissions management strategy*. NSW Environment Protection Authority.
NSW EPA. (2016a). Reducing locomotive emissions. Retrieved 26 April 2016, from http://www.epa.nsw.gov.au/esdsmoky/redlocoemis.htm
NSW EPA. (2016b). *Review of regulation of railway systems activities: Cost-Benefit Analysis*. Retrieved from http://www.epa.nsw.gov.au/resources/legislation/rail-regulation-review-cost-benefit-analysis-140657.pdf.
NSW Government. (2015). *NSW Government responses to the Upper House Inquiry recommendations*. NSW Parliament House: Provided by the Minister for the Environment to the Clerk of the Parliaments.
NSW Health. (2010). *Respiratory and cardiovascular diseases and cancer among residents in the Hunter New England Area Health Service*. NSW Department of Health, Population Health Division. Retrieved from http://www.health.nsw.gov.au/environment/Publications/HNE-Respi-Cardio-Disease.pdf.
NSW Minerals Council. (2016). Coal Train Dust Management - Hunter Valley Coal Industry.
NSW OEH. (2015). *New South Wales Air Quality Statement 2015*. NSW Office of Environment and Heritage, Retrieved from http://www.environment.nsw.gov.au/resources/aqms/160036-nsw-air-quality-statement-2015.pdf.
NSW Office of Environment and Heritage. (2016a). Beresfield air quality monitoring site Retrieved 28 March 2016, from http://www.environment.nsw.gov.au/aqms/sites/beresfield.htm

NSW Office of Environment and Heritage. (2016b). New South Wales Air Quality Statement 2015. from http://www.environment.nsw.gov.au/resources/aqms/160036-nsw-air-quality-statement-2015.pdf

NSW Planning and Environment. (2012). Duralie Coal Extension Project_MOD 1_Rail Hours Extension.   Retrieved 2 June, 2016, from http://majorprojects.planning.nsw.gov.au/index.pl?action=view_job&job_id=5176

NSW Planning Assessment Commission. (2015). D364/15 - Port Waratah Coal Terminal 4 - determination.   Retrieved 2 June, 2016, from http://www.pac.nsw.gov.au/Projects/PACDeterminations/tabid/104/ctl/viewreview/mid/459/pac/479/view/readonly/myctl/rev/Default.aspx

OEA. (2015). Draft Environmental Impact Statement for the Tongue River Railroad. U.S.: Prepared by the Surface Transportation Board's Office of Environmental Analysis.

Ostro, B, Hu, J, Goldberg, D, Reynolds, P, Hertz, A, Bernstein, L, & Kleeman, MJ. (2015). Associations of Mortality with Long-Term Exposures to Fine and Ultrafine Particles, Species and Sources: Results from the California Teachers Study Cohort. *Environmental Health Perspectives, 123*(6), 549-556. doi: 10.1289/ehp.1408565

PAE Holmes. (2010). Impacts of fugitive dust from coal trains in NSW - Stage 1 gap analysis: Prepared for Australian Rail Track Corporation (ARTC).

Pedersen, M., Gehring, U., Beelen, R., Wang, M., Giorgis-Allemand, L., Nybo Andersen, A., Basagaña, X., Bernard, C., Cirach, M., Forastiere, F., de Hoogh, K., et al. (2016). Elemental Constituents of Particulate Matter and Newborn's Size in Eight European Cohorts. *Environ Health Perspect, 124*(1). doi: 10.1289/ehp.1409546

Peters, A, Skorkovsky, J, Kotesovec, F, Brynda, J, Spix, C, Wichmann, HE, & Heinrich, J. (2000). Associations between Mortality and Air Pollution in Central Europe. *Environmental Health Perspectives, 108*(4), 283-287.

Pope, CA III, Burnett, RT, Thun, MJ, Calle, EE, Krewski, D, Ito, K , & Thurston, GD. (2002). Lung Cancer, Cardiopulmonary Mortality, and Longterm Exposure to Fine Particulate Air Pollution. *Journal of the American Medical Association, 287*(9), 1132-1141. doi: 10.1001/jama.287.9.1132.

Pope, CA III, Burnett, RT, Thurston, GD, Thun, M.J, Calle, EE, Krewski, D, & Godleski, JJ. (2004). Cardiovascular mortality and long-term exposure to particulate air pollution: epidemiological evidence of general pathophysiological pathways of disease. *Circulation, 109*(1), 71-77. doi: 10.1161/01.CIR.0000108927.80044.7F

Pope, CA III, & Dockery, DW. (2006). Health effects of fine particulate air pollution: Lines that connect. *Journal of the Air and Waste Management Association, 56*, 709-742. doi: 10.1080/10473289.2006.10464485

Port Authority of New South Wales. (2016). Trade Statistics.   Retrieved 24 March 2016, from http://www.newportcorp.com.au/site/index.cfm?display=111694

Raaschou-Nielsen, O, Andersen, Z. J., Beelen, R., Samoli, E., Stafoggia, M., Weinmayr, G., Hoffmann, B., Fischer, P., Nieuwenhuijsen, M. J., Brunekreef, B., Xun, W. W., et al. (2013). Air pollution and lung cancer incidence in 17 European cohorts: prospective analyses from the European Study of Cohorts for Air Pollution Effects (ESCAPE). *Lancet Oncol, 14*(9), 813-822. doi: 10.1016/s1470-2045(13)70279-1

Rahai, HR. (2008). Development of an exposure model for diesel locomotive emissions near the Alameda Corridor. Center for Energy and Environmental Research and Services (CEERS): Department of Mechanical and Aerospace Engineering, California State University Long, Beach and and METRANS Transportation Center USC.

RAND Corporation. (1998). Monitoring for Fine Particulate Matter.

Rogers, Z, Whelan, J, & Mozeley, F. (2013). Coal dust in our suburbs: a community-led study of particulate pollution in Newcastle and the Lower Hunter coal train corridor. Coal Terminal Action Group Dust and Health Steering Group: Coal Terminal Action Group.

Ryan, L, & Malecki, A. (2015). Additional Analysis of ARTC Data on Particulate Emissions in the Rail Corridor. On behalf of accessUTS Pty Ltd: Prepared for the NSW Environmental Protection Authority.

Ryan, L, & Wand, M. (2014). Re-analysis of ARTC Data on Particulate Emissions from Coal Trains. On behalf of accessUTS Pty Ltd: Prepared for the NSW Environment Protection Authority.
Sangkapichai, M , Saphores, JM, Ogunseitan, O, Ritchie, SG, You, SI, & Lee, G. (2010) An Analysis of the health impacts from PM and NOx emissions resulting from train operations in the Alameda Corridor, CA. *Faculty Research*: University of California Transportation Center.
Simpson, R, Williams, G, Petroeschevsky, A, Best, T, Morgan, G, Denison, L, Hinwood, A, Neville, G, & Neller, A. (2005). The short-term effects of air pollution on daily mortality in four Australian cities. *Australian and New Zealand Journal of Public Health, 29*(3), 205-212. doi: 10.1111/j.1467-842X.2005.tb00758.x
Spencer-Hwang, R, Soret, S, Knutsen, S, Shavlik, D, Ghamsary, M, Beeson, WL, Kim, W, & Montgomery, S. (2015). Respiratory Health Risks for Children Living Near a Major Railyard. *J Community Health, 40*(5), 1015-1023. doi: 10.1007/s10900-015-0026-0
Stanek, L.W, Sachs, J.D, Dutton, S.J, & Dubois, J.J.B. (2011). Attributing health effects to apportioned components and sources of particulate matter: An evaluation of collective results. *Atmospheric Environment, 45*(32), 5655-5663. doi: 10.1016/j.atmosenv.2011.07.023
Straif, K, Cohen, A, & Samet, J. (2013). *IARC Scientific Publication No. 161 Air Pollution and Cancer*. Lyon: International Agency for Research on Cancer, World Health Organization.
The Bloomfield Group. (2014). Bloomfield Colliery - Annual Envirnomental Management Report: Bloomfield Collieries Pty Ltd.
The Senate. (2013). *Impacts on health of air quality in Australia - Chapter 4*. Commonwealth of Australia: Canberra: The Senate Community Affairs Committee Retrieved from http://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Community_Affairs/Completed_inquiries/2010-13/airquality/report/c04.
Thurston, GD, Ahn, J, Cromar, KR, Shao, Y, Reynolds, HR, Jerrett, M, Lim, CC, Shanley, R, Park, Y, & Hayes, RB. (2015). Ambient Particulate Matter Air Pollution Exposure and Mortality in the NIH-AARP Diet and Health Cohort. *Environmental Health Perspectives, (Advanced Publication)*. doi: 10.1289/ehp.1509676
Tunra Bulk Solids. (2012). Dust Emission Investigation on 6 Xstrata Coal Samples. Tunra Bulk Solids Handling Research Associates, Division of Newcastle Innovation Ltd.: Newcastle Institute for Energy and Resources (NIER).
US EPA. (2009). *Integrated Science Assessment for Particulate Matter*. Prepared by the National Center for Environmental Assessment - RTP division, Office of Research and Development, U.S. Environmental Protection Agency.
US EPA. (2016a). Emission Standards Reference Guide. Retrieved 8 March 2016, from http://www3.epa.gov/otaq/standards/nonroad/locomotives.htm
US EPA. (2016b). Particulate Matter (PM). doi:https://www3.epa.gov/pm/
van Donkelaar, A, Martin, R, Brauer, M, Hsu, C, Kahn, R.A, Levy, R.C, Lyapustin, A, Sayer, A.M, & Winker, D.M. (2016). Global Estimates of Fine Particulate Matter using a Combined Geophysical-Statistical Method with Information from Satellites, Models, and Monitors. *Environ. Sci. Technol., 50*(7), 3762-3772.
van Donkelaar, A, Martin, R.V, Brauer, M, & Boys, B.L. (2015). Use of Satellite Observations for Long-Term Exposure Assessment of Global Concentrations of Fine Particulate Matter. *Environmental Health Perspectives, 123*(2), 135-143.
WHO. (2013a). Health risks of air pollution in Europe - HRAPIE project - Recommendations for concentration-response functions for cost-benefit analysis of particulate matter, ozone and nitrogen dioxide: Prepared for the Regional Office for Europe, World Health Organization.
WHO. (2013b). *Review of evidence on health aspects of air pollution - REVIHAAP Project Technical Report*. The WHO European Center for Environment and Health, Bonn and WHO Regional Office for Europe.

WHO Working Group. (2004). Health Aspects of Air Pollution - answers to follow-up questions from CAFE: World Health Organization.

Zhou, Y., & Levy, J. I. (2007). Factors influencing the spatial extent of mobile source air pollution impacts: a meta-analysis. *BMC Public Health, 7*, 89. doi: 10.1186/1471-2458-7-89

APPENDICES

APPENDIX 1. TERMS OF REFERENCE

Review of rail coal dust emissions management practices in the NSW coal chain

The Government response to Recommendation 7 of the Inquiry into the Performance of the NSW Environment Protection Authority was that 'The Chief Scientist & Engineer has agreed to undertake a review of rail coal dust emissions management practices. This will include a review of the work the EPA has undertaken in relation to coal dust emissions along the rail corridor in the Hunter Valley, as well as review of environmental monitoring, the literature, and the environmental management practices of operators using the rail network."

In undertaking the review the Chief Scientist & Engineer will provide advice on coal dust and related emissions in the rail corridor, in particular:

1. Identify, describe and comment on:
    a. key issues, including current scientific knowledge and matters of expressed public concern
    b. initiatives in NSW and other jurisdictions to address issues, including measurement , prevention and management practices
    c. any gaps or issues arising
2. Describe advances in technology for sampling and monitoring air emissions from the coal chain in the rail corridor.

The review report will also include contextual information on air quality including dust and particulate emissions across the coal supply chain, and approaches used by NSW and other jurisdictions to measure, assess and manage these.

In undertaking the review the Chief Scientist & Engineer may consult with stakeholders and engage experts as needed.

The NSW Chief Scientist & Engineer will provide to the Minister for the Environment an initial report by 30 November 2015 and a final report by 31 March 2016.

APPENDIX 2. EXPERT WORKSHOP

Participants

Expert name	Organisation
Professor David Cohen	A/Head, Institute for Environmental Research, ANSTO
Dr Brendan Halliburton	Senior Research Scientist, Energy Technology, CSIRO
Dr Mark Hibberd	Principal Research Scientist, Oceans & Atmosphere, CSIRO
Dr Ian Longley	Senior Air Quality Scientist & Head, Impacts of Air Pollutants programme, National Institute of Water & Atmospheric Research (NIWA), New Zealand
Mr Kieran Lynch	A/Manager, Compliance and Assurance, NSW Environmental Protection Authority
Mr Alan Malecki	PhD candidate, University of Technology Sydney
Mr Andrew Mattes (facilitator)	Senior Environmental Specialist (Air Quality), NSW Roads and Maritime Services
Mr Matthew Riley	Director, Climate and Atmospheric Science, NSW Office of Environment and Heritage
Professor Louise Ryan	Distinguished Professor, School of Mathematical and Physical Sciences, University of Technology Sydney
Mr Anthony Savage	Manager, Air Technical Advisory Services Unit, NSW Environmental Protection Authority
Dr Ben Scalley	Deputy Director, Environmental Health Branch, NSW Health

Summary of workshop outcomes

The Review convened an expert workshop to consider the questions as posed in the Initial Report. The workshop discussed relevant contextual issues, an important one being ambient air quality and its measurement, and another being how air quality within and near the corridor can be measured and characterised.

Points of consensus from the workshop included that there is a good ambient air monitoring network in the Lower and Upper Hunter Valley and confidence in the data produced by this network, which is publicly available in near real-time (NSW Environment Protection Authority, 2016). Further, that there is a good general understanding of ambient air quality in the Hunter Valley, which is regarded as generally good by international standards notwithstanding some exceedances of National Environment Protection Measure (Ambient Air Quality) standards (NEPM AAQ) (Environment and Climate Change Canada, 2016).

As discussed in the Initial Report, and which workshop participants concurred with, there is still uncertainty about air quality within and near the rail corridor itself. Specifically, participants noted that we don't yet understand well enough the emission rates, sources, variable contribution from different sources (including what proportion is coal) or particle size and how dust is dispersed and deposited. Further, while studies show some dust 'signatures' with the passage of trains (Higginbotham et al., 2013; Katestone Environmental Pty Ltd, 2013), it remains unclear if the increment of change in dust levels is sufficient to affect health.

One point of discussion in the workshop was an apparent lack of relationship between the number of coal train movements and local NEPM AAQ levels (outside the rail corridor) over time. There has been an approximately 58% increase in coal train movements on the Hunter rail line from 38 loaded trains per day in 2009 to 60 per day in 2015 (Australian Rail Track Corporation Ltd, 2009, 2015). Coal exports currently represent 96% of the total volume of freight through the

Port of Newcastle (Port Authority of New South Wales, 2016). However, there has been very little or no change in NEPM monitoring data at a site 250-300m from the rail line over this time period (Beresfield AQMS) (NSW Office of Environment and Heritage, 2016a). A number of hypotheses regarding this apparent lack of association were raised in the workshop. These hypotheses and related questions include whether the relationship between train volume and monitoring results of ambient air levels might be non-linear; whether particulate levels closer to the rail corridor might be higher and how quickly the levels fall off with distance from the track; whether it is possible that in specific places an increase in train movements may have significant localised rather than generalised impacts, and whether dust emissions are related to some property of train movements other than train volumes. There is variability in the volume of train movements in different sections of the corridor (e.g. multi-track and higher volume in urban areas), raising the question of whether averaging of data is obscuring variability.

Previous studies raise further questions. For example, the re-analysis of the ARTC study by Professor Ryan observed that the concentration of particulates measured on the passing of trains may be impacted by rain, while variation between trains didn't appear attributable to either the speed of trains or number of locomotives pulling a coal train (Ryan & Malecki, 2015).

Other questions that emerged during the workshop included whether the height of monitors used for within-corridor studies affected results. After canvassing these and other questions, the workshop turned to the task of considering of how best to address them, discussed in the following sections.

1. Addressing the knowledge gaps – study design and sequencing

The Review workshop explored approaches to address uncertainties, questions and unknowns associated with rail coal dust and related emissions. The primary questions around which much of the conversation focussed were drawn from the Initial Report, and were:

1. Is there anywhere in or near the rail line where air quality exceeds Australian standards and, if so, what is the shape and nature of the air particulate profile of the region near the rail line and are the levels higher at all times or in certain time periods?
2. And then, are there any mitigation techniques that would ensure the air quality within this region near the rail line stays within the regulation levels?

2. Developing solutions

In considering approaches to tackle the two questions put to the workshop, a number of study design elements emerged from discussion that have been set out below. These are not necessarily exhaustive but they help set the scene and rationale for the approach to developing a study that emerged through the course of the workshop. These elements are:

- while recognising the importance of assessing impacts against standards (as set out in Question 1 of the Initial Report), it is also important to consider the consequences to human health of increases in particulate exposure, length of exposure, the size of the affected population and scale of increased concentration i.e. the temporal, spatial and locational dimensions of the problem
- particulate size data (i.e. $PM_{2.5}$, $PM_{2.5\text{-}10}$ etc.) is important for characterising the emission sources; and calculating exposures and health impacts given it is the respirable fraction (less than PM_{10}) that is most important for health
- as a key end-user, it is important to understand NSW Health data requirements to ensure that questions in any additional rail corridor studies are appropriately framed and the data generated from them are readily useable, noting that health impacts are estimated using associations determined from studies such as long term cohort and time series studies.
- it is essential to understand, as best as possible, the contribution of different sources of particulates so that if impacts are identified, this information can be used to inform effective mitigation choices.

The discussion also included consideration of challenges in collecting and interpreting data.

3. What knowledge gaps need to be addressed?

In considering Question 1 above, it can be broken into two parts: a question about particulate

levels within the corridor and at its edge, discussed further in subsections 3.1-3.2; and a second question on how far outside of the corridor the dust plume reaches and how this changes with time, discussed further in subsection 3.3.
The discussion of Question 2 in the workshop hinged on how to differentiate different types of particles to determine their source and dispersion pathway, thus informing mitigation approaches; discussed further in subsection 3.4.

3.1 Particulate levels in the corridor

The gaps in knowledge for dust in and near the corridor can be summarised in the following set of questions: What are the levels of particulates within the corridor when there are no trains? What are the levels when there are trains? What are the levels at the edge of the corridor, what are the levels at the point where the closest residents live? How do these compare with ambient background levels? If there is a statistically significant increase in corridor levels compared with background levels, how does this relate to health outcomes (an increased risk of mortality or morbidity)?

3.2 Short term exposures and baseline levels

One identified challenge is how to handle data from individual train movements and similar short time periods. Currently in the health literature the shortest exposure periods for particulate matter with measured health impacts are 24 hour exposures. Should the data be aggregated to produce 24-hour averages?

Another challenge discussed in the workshop, and of particular relevance for the Hunter region, was that in existing studies there were few ‘no train’ periods in the denser urban areas in Newcastle. This is relevant as ‘no train’ periods are often used as a proximal measurement for the baseline levels, but evidence suggests that elevated dust levels in the rail corridor persist for some time after the passage of trains(Higginbotham et al., 2013; Katestone Environmental Pty Ltd, 2013). This was thought to lead to difficulties when trying to compare ‘with train’ and ‘no train’ sampling periods.

3.3 Shape and extent of any plume

Assuming that there are dust plumes raised in the corridor, any proposed study would want to examine whether the plume extends beyond the corridor, and to what distance and with what particle concentration profile.

Possible study design options and methods to address this question were discussed in the workshop, and were informed by experience from air quality studies undertaken in the Hunter Valley as well as road and tunnels studies that have examined emissions and particulate dispersion.

It was agreed in the workshop that care is needed when drawing on road and tunnel study designs for the purposes of the rail corridor due to differences in volume, concentration and the height of pollutant sources. However, road and tunnel study methodologies are well-established and provide valuable pointers in terms of study design and ‘drop off’ distances. For example, on even the busiest motorways $PM_{2.5}$ falls back to ambient levels at 150-250m from the road; NO_2 at around 250m except in unusual cases (Kheirbek, Johnson, Ito, Anan, Matte, Kass, Eisl, Gorczynski, Markowitz, & Ross, 2015; Longley, Kingham, Dirks, Somervell, Pattinson, & Elangasinghe, 2013; Morawska, Vishvakarman, Mengersen, & Thomas, 2002).

While existing studies in the Hunter rail corridor have generally used a single monitor and compared ‘with train’ and ‘no train’ periods to identify a ‘train signature’, another more detailed method (often used in road studies where there can be continuous traffic) is to place monitors and record measurements on both sides of the source (the road or, in the context of the proposed study, the rail corridor) and, if possible, with wind conditions perpendicular to the source. The difference between the ‘ambient’ (upwind) and ‘disturbed’ (downwind) is effectively attributable to emissions from the source. This comparative method also effectively addresses issues of contamination from different sources.

3.4 Distinguishing sources to inform mitigation approaches

If particulates are measured at higher concentrations within or near the corridor, sample characterisation is critical to understand the nature of these particulates, their sizes, whether they can be attributed to a source and the relative contribution between different sources or particle types.

Approaches to measuring dust and particulate samples were discussed during the workshop and the experts agreed that it is important to characterise and apportion relative source contributions (e.g. coal, brake or grain dust; diesel exhaust; soil or sea salt) and that mixed methods may be used for this purpose. For example, carbon monoxide (CO) or nitrous oxide gas (NO_X) detected with $PM_{2.5}$ would be a means to specifically identify diesel exhaust; real particle counters are an efficient technology that measure in real time and will capture coarser particles i.e. 10-20µm; nephelometry and other visible light techniques can measure carbon in the dust and distinguish coal and non-coal particulates; and, filter papers with air drawn through them can be analysed using microscopic techniques.

4. A staged monitoring and measurement study

The workshop canvassed a range of desk top and in-field studies, with options refined through a process of asking what could be done; what is essential to deliver good data on the most pressing questions; and what is the most efficient sequencing approach to any additional work in terms of time, effort and cost.

The workshop proposed a staged approach to gathering the most essential data, working through questions sequentially and using a mix of desktop modelling and in-field studies, described below. It also outlined key requirements and considerations that should inform the design and execution of the proposed stages, summarised in Table 1.

4.1 Proposed Study – Stage 1 (Part A) – developing an evaluation framework

Stage 1 (Part A) involves an initial desktop study to develop a risk evaluation framework that relates incremental increases in particulate exposure to health impacts established through large scale epidemiological studies.

Stage 1 Part A of the proposed study involves determining the heath endpoints to be used, drawing on available literature, and undertaking mathematical calculations to establish what amount of change (of particulates) would need to be observed in the rail corridor (the ‘exposure’) that can then be related back to an increased risk to human health (endpoints – the response”) – e.g. all-cause mortality, mortality or morbidity due to cardiovascular disease etc. The end result will be an evaluation framework including risk ranges as described below.

Table 1: Indicative study design, questions and methods

Element	Stage 1 – within the corridor	Stage 2 – beyond the corridor
Activity	Part A: Desktop – develop an evaluation framework Part B: In-field measurement, additional desktop calculations and projections	In-field Stage 2 is dependent on outcomes of Stage 1 – characterise source and exposure
Questions	Part A: • What are the heath endpoints to be used? • What increased concentrations of particulates would need to be observed in the rail corridor compared with background levels (incremental change) that relate to increased risks of identified health endpoints? Part B: • What particulate concentrations are in the corridor? What are the corresponding background levels? • If there is a difference, is it statistically significant? • How does the measured particulate increase correspond to the evaluation framework established in Part A?	• Stage 2 would involve determining how far from the corridor these elevated levels persist. • What is the profile and distribution of the plume, how far does it extend from the rail line? • What locations (e.g. residential) would be expected to have the highest dust levels due to the corridor (upper limit)? Are the levels of increased particulate concentrations in these locations statistically significant? How do they correspond to the evaluation framework established in Stage 1 Part A? • What is the relative contribution of sources and apportionment of the

	• What are the character and sources of contributing concentrations?	particulates from different sources?
Methods	Part A: • Make a decision about what health end-points would be appropriate to use. • Relate increments of particulate concentration increase with health endpoints identified through large scale health studies available in the literature. Part B: • Design study, e.g. decide location(s) and instrumentation based on best available knowledge. • Establish in-field rail corridor monitoring study to capture particulates and other data (e.g. meteorological, train); compare in-corridor and background (out of corridor) results and determine any statistically significant differences. • If a statistically significant difference is identified, consider this difference in the context of the evaluation framework from Part A. • Additional desktop work may include undertaking additional analyses of data from already available studies and other sources to better understand magnitude of change and variations due to passing trains	• Extend in-field monitoring out from corridor, with monitors placed at increasing distances from the rail line. • Particulate samples collected to determine source

4.2 Proposed Study – Stage 1 (Part B) – evaluating in-corridor levels

Stage 1 Part B would establish study methods to gather the relevant data, and applying these to the evaluation framework established from Part A.

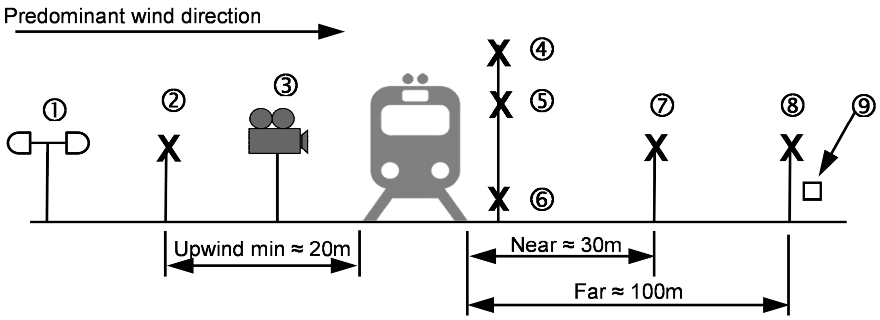
Stage 1 (Part B) involves an in-field study to measure particulate concentrations in the rail corridor and compare these with out-of-corridor levels (measured through the ambient monitoring network) to obtain evidence of variation (increase). If observed, the level of increased concentration of particulates is then assessed as to whether it is statistically significant over the relevant timeframe (e.g. annual average increase). If the change is statistically significant, then this would be assessed against the evaluation framework in Part A.

It is anticipated that it may take 2-12 months to gather sufficient data. More than one corridor location may be studied to better understand possible contributing factors such as smooth or fast train travel, gradient etc. This may also help inform the stage 2 study design.

Additional desktop work may include analyses of data from already available studies and other sources to better understand magnitudes of change and variations due to passing trains.

The in-field components of the proposed study are illustrated in Figure 1 with possible alternatives (adapted from knowledge of road and rail studies) noted in the legend. It is emphasised that the figure is illustrative of the proposed approach only, and includes elements from both Stage 1 and Stage 2. Factors including design, methods, instrumentation, distances and locations would all need to be subject to detailed and fine-grained analysis when scoping the study (should further work be undertaken), ensuring all elements are appropriate to the question being asked and variables being measured.

Figure 7: Possible field study elements, sequencing and substitution options for Stages 1 and 2



Legend

	Description	Comment/ alternative options
1	Automatic weather station as close as possible to air monitors including but not confined to wind speed and direction, solar radiation, temperature, relative humidity, precipitation, barometric pressure	Essential part of Stage 1 Part B Weather station may preclude need for 'both side of tracks' and 'upwind' monitor [legend #2] if set to trigger under specific conditions [e.g. wind direction]
2	Upwind ambient monitor, far enough from rail line to avoid turbulence (≈ 20m). Each monitor 1s – 1min resolution	Relevant to background and differential component compared to downwind monitors but may not be required - see legend #1
3	Elevated video camera for recording train movements (capable of recording timestamp to nearest second).	Preferred part of Stage 1 Part B - address challenge of train identification experienced in previous studies associated with train volumes and concurrent passing
4	Near monitor at elevated level to measure diesel exhaust plume Placement of this monitor critical to obtain most useful results (could be subject of initial pilot or test study)	Essential part of Stage 1 Part B Placement of monitor critical to obtain valuable results Locate as close as possible to rail line, while accounting for turbulence effects
5	Near monitor at mid elevated level for top of wagon. Placement of this monitor critical to obtain most useful results (could be subject of initial pilot or test study)	Essential part of Stage 1 Part B Placement of monitor critical to obtain valuable results Locate as close as possible to rail line, while accounting for turbulence effects Monitoring could also be placed at the boundary of the rail corridor to ascertain drop-off from the rail line.
6	Near monitor at low level to measure dust generated from track and surrounds by movement of passing train and possibly from bottom of wagon Placement of this monitor critical to obtain most useful results (could be subject of initial pilot or test study)	Essential part of Stage 1 Part B Locate as close as possible to rail line, while accounting for turbulence effects
7	Downwind monitor at distance of nearest likely receptor (e.g. immediately outside rail corridor fence or closest residence - 30m is an exemplar approximation only and will be subject to detailed design considerations)	Stage 2 study
8	Additional downwind monitor (for background)	May not be required - depending on study location, may be possible to use existing network monitor for comparison
9	Filter collection point [using e.g. QEMSCAN analysis] (potentially co-located with each monitor)	Preferred part of study, essential for TSP concurrent data collection

Design, distances and locations are subject to detailed study considerations and scoping – the figure is illustrative of the approach

Key requirements and considerations for undertaking the proposed in-field study identified by workshop participants are summarised in Table 2. These include measurements to be taken;

meteorological and train data for collection and analysis; accounting for in-field factors and confounders; and managing the study to ensure data collected are robust and useable.

Table 2: Key requirements and accounting for in-field factors

<table>
<tr><th>Dimension</th><th>Elements</th></tr>
<tr><td>Focus</td><td>Identify and quantify any increase in PM concentrations due to emissions from the rail corridor</td></tr>
<tr><td>Measurements to be taken</td><td>Measurement of total suspended particulates (TSP), PM_{10} and $PM_{2.5}$</td></tr>
<tr><td>Meteorological data</td><td>Include meteorological data collection and analysis
Proximate location of meteorological instruments to monitoring instruments (i.e. as close to study site as possible) without compromising the ability to deploy an anemometer mast (10m height)
Data collected includes, but is not limited to:
wind parameters – speed, direction, turbulence
rainfall amount, duration and timing (soil moisture content more helpful, but difficult to gather)
temperature; humidity</td></tr>
<tr><td>Train data</td><td>Include collection of train data and analysis
Capture through rail monitors or image capture (video and software)
Ability to identify each type: freight or passenger; speed; length of train, number of locomotives; number of wagons; cargo (when cargo is coal, source and characteristics); speed etc.
Ability to identify train, operator and date/time (to the nearest second) to determine operating statistics including type of coal
Ability to identify and distinguish multiple trains passing simultaneously</td></tr>
<tr><td>In field factors</td><td>Location: avoid or account for confounding factors e.g. large roads near rail line (where road diesel could contribute); proximity to other coal sources (e.g. mines, power stations, stockpiles) and other activities; atypical or unrepresentative topography and meteorology; track gradient; concentrations adjacent to track and also at perimeter of corridor
Turbulence: site monitoring equipment to measure and/or account for impacts of passing trains
Height of monitors: various to account for different source heights (e.g. ground level re-entrainment; wagon lift-off; locomotive exhaust plume)
Track gradient and junction points: may influence emission levels and should be considered in study siting choices. This may result in a trade-off in terms of speed (slower at these points) but train speed may or may not be significant (load potentially more influential) - review available data as part of study design to clarify if there are any thresholds that have an impact
Wind and track direction: the Hunter rail line generally follows the direction of the valley, which overall runs north-west to south-east. The predominant wind directions are also generally along the valley (with north-westerlies in winter and south-easterlies in summer), so there are relatively few periods with cross-winds across the rail corridor. However it may be possible to design a study so monitors are ‘triggered’ to capture cross-wind conditions and data, avoiding the need for additional or separate components of work
Security: site the monitoring equipment to avoid tampering and vandalism.
Rain: it is important to include the potential of rain to change PM emission rates, for example wet soil and track reducing dust generation. The re-analysis of the ARTC data study indicated a reduction in particulate levels measured following rain (Ryan & Malecki, 2015) but the result is not considered definitive. This effect could potentially be examined through a designed ‘wetting track’ study or ‘natural’ study by accurately monitoring meteorology data and monitors are triggered by rain. The latter might avoid the need for additional or separate components of work</td></tr>
<tr><td>Instrumentation</td><td>utilise standard, comparable methods and calibrated instrumentation to ensure robust and comparable data</td></tr>
</table>

4.3 Proposed Study - Stage 2 – measuring the particulate profile out from the corridor

If Stage 1 Part B shows increased levels of particulates in the rail corridor that are statistically significant and are relevant to the identified health endpoints, then Stage 2 would be undertaken.

Stage 2 involves an extension of in-field studies by locating a number of monitors at selected locations further out from the rail line to measure the extent of the dust plume from the rail line, thus providing a profile or cross-section of the plume to understand how far it reaches from the track, at what distance the concentrations drops back to background, and other characteristics.

The nearest monitoring site to the corridor perimeter would be determined through further desktop work to understand where the most exposed properties would be (those houses closest to the corridor are likely to be in the order of tens of metres from the track) to understand the upper bound of exposure. The particulate levels measured at this location would also be compared with in-corridor and background levels to determine statistical significance, and then assessed against the evaluation framework.

If the levels here (at this close proximity) didn't demonstrate a statistically significant increase, (being the upper bound worst case scenario) then it would be unlikely that locations further out from the track would be higher. Consideration could then be given to progressing with the study.

Stage 2 would also include sampling to further explore what particulates people may be exposed to – i.e. whether coal or other particulates and relative contributions of different sources. Consideration of appropriate risk management and mitigation strategies would follow the answers to these questions.

APPENDIX 3. SUMMARY OF STUDIES: WHAT THEY TELL US

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
General or comprehensive studies (including literature review/gap analysis/modelling/mitigation/etc.)				
Literature Review of Coal Train Dust Management Practices Dec 2014/ final report/ NSW (reviews other jurisdictions) (Katestone Environmental Pty Ltd, 2014)	Katestone Environmental Pty. Ltd. for NSW EPA	Focus on current literature surrounding coal train dust management practices and measures relevant to the Hunter Valley rail corridor and other coal rail corridors in NSW Focus: rail corridor and ambient	Literature review, which: ● Explains the regulatory framework for rail coal dust in Australia (includes NSW, Qld - which includes Aurizon as both the 'above' and 'below' rail operator and the US Railway Regulations. ● Describes and evaluates measures used both nationally and internationally to control coal dust emissions from trains, including coal loading and unloading, wind erosion from coal in wagons and coal spillage in the rail corridor. ● Ranks techniques and studies according to their perceived effectiveness or relevance to NSW.	Literature indicates: ● Dust levels increase when trains pass for loaded, unloaded, freight and passenger; some studies suggest higher levels with loaded and unloaded coal trains ● No exceedances of NEPM standards were found at monitoring stations in or near the rail corridor when monitors were used in accordance with Australian standards ● Effectiveness of most management practices not well documented in literature (except water or veneer suppressant which are claimed to reduce top of wagon emissions by 50-99%) ● Wagon lids are estimated to reduce dust off the top of the wagons by 99% but have significant disadvantages ● To prevent coal dust emissions from handling, keep coal moisture above DEM level and load/unload with shed ● Veneering costs for NSW were estimated at \$0.02- 0.04 per tonne; water at \$0.005 per tonne
Impacts of fugitive dust from coal trains in NSW – stage 1 gap analysis Feb 2010/ final report/ NSW (PAE Holmes, 2010)	PAE Holmes for ARTC	Undertaken by the ARTC as mandated by a Pollution Reduction Program (PRP 4) in their Environmental Protection Licence (EPL) to investigate technologies to reduce fugitive coal dust emissions associated with rail transport in NSW. Study to determine extent of issue, any potential environmental harm and possible mitigation measures. Focus: rail corridor	Stage 1- desktop review of literature, (including Connell Hatch (2008) report and how applies to NSW) and data - gap analysis In particular, the study investigated how applicable the Connell Hatch report for Queensland Rail (2008) was to the situation in NSW.	The gap analysis, in reviewing Connell Hatch (2008), accepted that erosion off the surface of the wagon is likely to be the major contributor to emissions from wagons. But it acknowledged many factors would be different and those needed investigation. The report notes that in order to fully understand the issue in NSW and evaluate the effectiveness of mitigation measures (compared with Queensland), the following needs to be analysed for NSW: ● increase in coal transport ● dust extinction moisture (DEM) levels for NSW coals ● wind speeds for dust lift off of NSW coals ● other NSW coal property data (e.g. fines content, density, strength, etc.)

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
				• train speeds in NSW • evaluate differences in TSP emission estimates between Connell Hatch report and other studies • applicability of veneering studies for NSW • loading/unloading practices in NSW • potential contribution of coal spillage and re-suspension Note: Since the report's publication, NSW industry (see NSW Mining website) has been undertaking wind tunnel testing, DEM testing, testing effectiveness of veneering, etc. Some of the outcomes of this work are not publically available.
Final Report - Environmental Evaluation of Fugitive Coal Dust Emissions from Coal Trains Goonyella, Blackwater, and Moura Coal Queensland Rail Systems March 2008 / final report/ Qld (Connell Hatch, 2008)	Connell Hatch for Queensland Rail Limited	Environmental Evaluation conducted by Connell Hatch for QR Limited (later Aurizon) in response to a notice by the Queensland EPA to identify, quantify, assess risk and propose mitigation measures relating to fugitive dust emissions from coal trains. Aim to quantify ambient concentrations of coal dust in rail corridor in Central Queensland. Analysis to quantify source of dust emissions and evaluate various mitigation options: (e.g.: Appendix C - *Wind Tunnel Program to Determine the Extent of Dust Lift-Off From the Surface of Typical Coal Types When Treated With Surface Veneer Chemicals Under Simulated Rail Transport Operations* Appendix D - *Wagon and load profiling wind tunnel –*	• Reviewed three previous rail corridor monitoring studies • Undertook TSP monitoring over 4 months at 14 sites (6 within corridor) using Partisol monitors • Compared against air quality goals for TSP and PM10 • Dispersion modelling using Cal3QHCR (Gaussian line source model) • Literature review of emissions factors and estimation of dust lift off from exposed surface and from other sources • Desktop analysis of the cost benefits of various mitigation options The study characterised the dust emissions rate from the surface of the wagons, leakage from doors, wind erosion of spilled coal, residual coal in empty wagons and parasitic load. Methods used included: **Surface of wagons:** • literature review • a mathematical model derived from a computational fluid dynamics (CFD) model by Witt et al. 1999 • wind tunnel testing to confirm the CFD model • model estimated that rail wagons would lose an average of 9.6 g/km/wagon (or 0.0035 percent) of their total load	• Concluded that TSP did not exceed the guideline of 150 µg/m3 (EPP (Air) Goal) over monitoring period for each site • Assuming PM10 is 50% of TSP and comparing TSP results to PM10 NEPM standards, they concluded that exceedances of PM10 at monitoring sites were unlikely • Contribution by coal dust in cases of exceedances found to be minor • Based on modelling results, concluded that exceedances beyond the corridor are unlikely • The emission rate of coal (TSP) is estimated to be 5416 tonnes per year for the Blackwater, Moura and Goonyella systems, with and estimated growth to 7882 tonnes per year by 2014/15 • At least six ambient air quality monitoring studies were conducted since 1993 to investigate PM adjacent to the coal rail corridor, with all concluding that they did not find the potential for any adverse health impacts to those inside or outside of the rail corridor • Dispersion modelling suggested ground-level PM10 is unlikely to exceed air standards 10 metres from the tracks. Assumptions/inputs to model was not provided in report. • The Callemondah (2007) and Moura, Goonyella and Blackwater studies indicate

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
		University of Sydney and Computational Fluid Dynamics) Focus: rail corridor and ambient	**Leakage from doors** • Refer to *Coal Leakage from Kwik-Drop Doors - Coal Loss Management Project* detailed under *Veneering studies/testing effectiveness of mitigation techniques* below.	that the effect of coal dust emissions on ambient dust concentrations is measureable at 15 m from the rail centreline, with some mines having dustier coal types. • Estimated 80% of coal dust emissions from surface of wagon; 9% spilled coal; 6% door leakage; 4% parasitic coal; 1% residual coal in unloaded wagons • Laboratory testing indicated that on seven typical coal types transported by QR Ltd. and five surface veneer products (applied at one L/m2) resulted in a significant reduction in emissions (dust lift-off) when compared to no treatment • Whilst wagon lids may reduce coal dust emissions, there are other factors that need to be considered - potential operational costs, reliability and maintenance requirements, and facility requirements. • Indicated that emission rates from the top of the wagon (i.e. coal lift-off) may increase by a factor of 5-10 when a unloaded train passes due to the increase in turbulence and the speed at which empty trains travel (up to 100 km/hr) • Wind erosion of spilled coal – A preliminary upper bound estimate of the amount of coal dust emitted from coal deposited in the corridor is 600 tonnes per annum. • Residual coal in empty wagons – On average, the worst-case coal carry-back was found to be 0.13 tonnes per wagon (CSIRO et al, 2007).
Draft Environmental Impact Statement, (relevant air quality sections) April 2015/ USA (OEA, 2015)	Tongue River Railroad Company, Inc.	The Tongue River Railroad is a planned rail line in Southern Montana that would connect the region around Ashland, Montana with a BNSF Railway line to the north. Chapter 4 describes the impacts on air quality that would result from	• In Chapter 4, the Surface Transportation Board's (Board) Office of Environmental Analysis (OEA) analysed the risks of airborne coal dust using US EPA approved methods to estimate emissions. • In Chapter 6, OEA also analysed how coal dust could affect human health if it were to be ingested by humans or to make its way into soil or water. **Appendix E, Air Quality, Emissions, and Modelling Data:**	**Coal dust and diesel emissions:** The OEA found that aggregate concentration of all types of particulate matter, including airborne coal dust, would be below air quality standards for particulate matter. The OEA determined that exposure would be within applicable standards and guidelines for all emissions including: • Locomotive exhaust emissions • Coal dust emissions from rail cars • Particulate matter emissions from wind erosion

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
		construction and operation of the railroad. Chapter 6 describes the impacts from coal dust on people, property, and ecosystems that could result from construction and operation of the railroad. Appendix E provides information on the inputs and emissions calculations used for estimating the BNSF Railway Company (BNSF) locomotive fleet emissions for operating the railway lines. It also provides information on the size distribution of coal dust particles. Appendix G provides the details of the modelling analysis of coal dust ingestion and its impacts on human health and ecological receptors. Focus: rail corridor and ambient	● This Appendix used concentration and deposition modelling to estimate coal dust emissions. ● OEA used the US EPA AERMOD dispersion model (U.S. Environmental Protection Agency 2004) with the estimated emission rates, along with meteorological data for the study area, to estimate the concentrations of airborne pollutants and the deposition of particulate matter that could result from operation of the proposed rail line. ● The emissions calculations were based on three coal production scenarios—low, medium, and high. ● OEA evaluated the locomotive emissions for the initial production year, along with intermediate years 2023 and 2030 and the full build-out scenario of 2037. ● OEA developed these estimates by modelling the coal dust emissions from the coal trains along with other key inputs, including hourly meteorological data, terrain data, land-use information, coal dust particle size, train speed, type of coal, and application of a topper agent. **Appendix G, Coal Dust Analysis:** ● This Appendix used a deposition model combined with a fate and transport model to estimate both human health and ecological impacts. ● In a search of the available scientific literature, OEA did not identify any scientific studies that specifically examined the human health risks associated with coal dust from moving rail cars.	• Exhaust emissions from motor vehicles delayed at grade crossings • Coal dust deposition • Visible airborne dust • Risk of wildfires and subsequent pollutant emissions OEA concluded that coal dust from rail cars on the proposed rail line would not affect human health.
Monitoring of particulate levels in or near the rail corridor				
Pollution Reduction Program (PRP) 4 - Particulate Emissions from Coal Trains Sept 2012/ study complete/ NSW Note: PRP 4.1 followed from	Environ Australia (for ARTC)	Pilot monitoring program by ARTC as mandated by PRP 4.1 to investigate whether coal trains and rail transport contribute to particulate levels along Hunter rail network	● Two monitoring sites in rail corridor at Metford and Mayfield were set up over one month using Osiris equipment to measure TSP, PM10, PM2.5 ● Wind direction and speed was recorded for each train passing ● Continuous measurements made whether trains or no trains	• At the Metford monitoring station, TSP, PM10 and PM2.5 concentrations recorded coinciding with all trains, including loaded coal, unloaded coal, freight and passenger were statistically greater than the ‘no train’ data set. • There was no significant difference between loaded and unloaded coal trains.

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
PRP4 Stage 1 Gap Analysis by PAE Holmes 2010 (see row 2 above) (ENVIRON, 2012b)		Focus: rail corridor		• At the Mayfield site, there was a statistical difference between the 'no train data' and the concentrations recorded to coincide with all of the train categories, including loaded coal, unloaded coal, freight and passenger for TSP and PM10. When examining PM2.5 and the 'no train data' there was only a statistical difference for the freight and passenger train types. • The Mayfield results were found to be unreliable due to high % of multiple trains passing, slow train speeds, difficulty matching pass by with train type. • The pilot didn't investigate compliance against standards or health assessment, as not in scope. Commented briefly on levels compared to Newcastle, and found to be slightly higher. Note: single monitor not equidistant to multiple parallel tracks
Pollution Reduction Program 4.2 Particulate Emissions from Coal Trains May 2013 / study complete/NSW (Katestone Environmental Pty Ltd, 2013)	Katestone Environmental Pty. Ltd. (for ARTC)	ARTC required under PRP 4.2 to undertake monitoring further to pilot (PRP4.1) at Metford The objective was to determine whether: • trains on the Hunter network are associated with elevated particulate matter concentrations; • loaded coal trains have a stronger association with elevated PM than unloaded coal trains or other trains on the network (and by inference contributing to ambient rail corridor particulate levels) Focus: rail corridor	• Used Osiris monitor for TSP, PM10, and continuous PM2.5 concentrations 3-4 metres from the nearest of four parallel tracks • Wind direction and speed were measured • Compared measurements with the concentration of particulate matter when no train was present.	• Passenger and freight trains were not associated with a statistically significant difference in TSP, PM10 and PM2.5 concentrations when compared with the concentrations recorded when no train was passing the monitoring station; loaded trains were associated for TSP only but unloaded trains were associated for TSP, PM10, and PM2.5. • There was no trend in concentration changes with train speed or ambient wind speed • When wind blew toward monitor, average increase in TSP, PM10, and PM2.5 for unloaded trains was 23%, 24%, 21% respectively; for loaded trains 14%, 14%, 11% respectively. The source of the dust wasn't examined. • The report showed a brief comparison of measured PM10 and PM2.5 24-hour levels against 3 OEH sites in the Hunter and generally found the levels at the study sites to be slightly higher, but limited data was provided in the report.

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
Re-analysis of ARTC Data on Particulate Emissions from Coal Trains Feb 2014 / study complete/NSW (Ryan & Wand, 2014)	Professor Louise Ryan from UTS	Particulate levels in or near the rail corridor Focus: rail corridor	The ARTC PRP 4.2 monitoring data was analysed using a variant of linear regression, with outcome variables corresponding to one of the four particulate measures (PM1, PM2.5, PM10 or TSP). The regression analysis took into consideration the likelihood of serial correlation due to the time-series nature of the data. Note: the ARTC data or report were also the subject of a July 2013 peer review by Dr Luke Knibbs and September 2013 by Professor Louise Ryan	Regression analysis conducted by Professor Ryan showed; ● evidence that PM levels were elevated when trains pass for TSP, PM10, PM2.5 and PM1 ● particulate levels were elevated in the few minutes before, during, and the few minutes after a train passed ● the effect was around 10% above background for both freight and coal trains (unloaded and loaded) ● elevated levels from passenger train was a smaller magnitude, though still mostly statistically significant except it was non-significant when a passenger train was passing on its own (no multiple passing) ● due to increased levels of the smaller particle sizes, diesel may be of more concern than coal dust Note: The advantage of regression analysis over the analyses undertaken in the Katestone (2013) report, is that it allows for simultaneous adjustment with respect to various confounding factors that may otherwise bias or distort the analysis.
Additional analysis of ARTC data on particulate emissions in the rail corridor Aug 2015 / study complete/NSW (Ryan & Malecki, 2015)	Professor Louise Ryan from UTS	Particulate levels in or near the rail corridor Focus: rail corridor	The regression modelling was continued with analysis including further data - precipitation records and the number of locomotives pulling each train. Precipitation data were made available from a monitoring station in Maitland that recorded rain (in mm) on a daily basis and another monitor in Cessnock that recorded data on a 30 minute basis.	● The reanalysis found that the number of locomotives had little impact on particulate levels. (Caveat: ARTC warned that they do not believe that the locomotive data are entirely accurate.) ● The author noted that the findings dispel, to some extent, the hypothesis that diesel exhaust explains a large proportion of the observed increases in particulate levels associated with trains passing. ● There was a strong association with previous day's rain in Maitland, suggesting that a key mechanism for the increased particulate levels was passing trains stirring up dust that had previously settled on the tracks. ● The impact of the previous day’s rain was the same, regardless of which type of train was passing.

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
Coal Dust in our Suburbs March 2013 / study complete/NSW (Rogers et al., 2013)	Coal Terminal Action Group - community monitoring study	Focus on PM exposure levels for people living in the rail corridor. 'Snapshot' of air quality in residential areas close to corridor and Port of Newcastle. Focus: rail corridor	Three Osiris DustTrak portable air monitors across 12 sites in the Lower Hunter measuring for PM1, PM2.5, PM10 at 1 or 10 min intervals over Dec 2012 and January 2013; wind speed and direction was monitored; averages were aggregated to 24hr average Data was compared against the closest EPA monitors at Newcastle, Beresfield, or Stockton	• 7 of 11 sites recorded exceedances to 24-hour PM10 NEPM standard; OEH monitors did not record exceedances • 1 of 11 recorded a PM2.5 24-hour exceedance of the advisory guidelines; OEH sites did not record exceedances Note: Osiris monitor is not a compliance monitor and as such, the results are stated as not suitable for comparison against NEPM ambient air quality standards; source of PM not identified as out of scope
Coal Train Pollution Signature Study August 2013 / study complete/NSW (Higginbotham et al., 2013)	Coal Terminal Action Group - community monitoring study	Study to investigate particulate signatures and increases in particulate levels from passing coal trains for residential areas close to rail corridor Focus: near the rail corridor and other coal facilities (ports, mines, etc.)	Used Osiris monitors to record continuous PM10, PM2.5, and PM1 from 15-17 July 2013 at Beresfield and Hexham averaging around 10 m from the rail corridor (8.6m to 23m). Wind speed, direction, train speed and type also recorded. Pre-train results measured during the 2 minutes before a train passes were compared against the measurements during the train's' passage. Monitors were calibrated against EPA monitor at Beresfield site	• 81% of coal trains produced a recognisable pollution signature; 19% did not. • Results focused on 8 signatures (of 73 measured train passings), finding that PM10 levels rose between 94% and 427% for loaded coal trains; an unloaded coal train signature increased 1210%; while coal trains pass, particulate pollution increase up to 13 times; freight trains showed much lower increases • The study asserted that unloaded coal trains were responsible for generating high pollution levels with a 60 ug/m3 increase over background levels compared with 16 ug/m3 for loaded coal trains • Passenger trains were found not to produce a perceptible signature while freight trains and the XPT did show signatures in some cases, but they were much smaller in comparison with those observed for coal trains and of shorter duration.
T4 Project Environmental Assessment Volume 5, Appendix M: Air Quality Assessment, Appendix F: Assessment of Rail Wagon Emissions 28 Feb 2012/ study complete/ NSW (ENVIRON, 2012a)	Environ Australia for PWCS	The air quality assessment focused primarily on emissions from the T4 site itself; however a screening analysis was undertaken of potential air quality issues related to particulate matter emissions from rail operations transporting coal to the T4 project area. Focus: modelling air	• The air emissions modelling was based only on dust emissions from the surface of the coal wagons and used the findings of Ferreira et al to derive emissions factors of 1.71 g/km/wagon and 8.57 g/km/wagon for semi-covered and uncovered wagons respectively. • A cross section of predicted maximum 24-hour average and annual average TSP concentrations of coal dust from semi-covered and uncovered rail wagons servicing the T4 project, were predicted	• Peak 24-hour average PM_{10} concentrations due to fugitive emissions from rail wagons on-route to the T4 project area, at a coal delivery rate of 120Mtpa, were predicted to be in the range of 3 to 13µg/m³ at a distance of 20m from the railway corridor. • The lower and upper estimates were based on semi-covered/uncovered wagons. • The lower range was considered negligible; however the upper range was considered significant depending on the baseline air quality en route and proximity of residences

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
		emissions within the rail corridor	using the transportation dispersion model CAL3QHCR, developed by the United States Environmental Protection Agency (USEPA). ● Fewer than 100 residences were estimated to be situated within 20m of the rail corridor between Newcastle and Muswellbrook.	to the rail corridor. Note: detailed assumptions/calculations were not provided.
Western - Metropolitan Rail Systems Coal Dust Monitoring Program Final report Oct 2013 / study complete/QLD (DSITIA, 2013)	The Queensland, Department of Science, Information Technology, Innovation and the Arts (DSITIA)	Air quality scientists at the QLD Department of Science, Information Technology and the Arts (DSITIA) independently assessed both health and nuisance impacts of dust from all sources at six sites along the rail corridor into the Port of Brisbane. Study commissioned by a group comprising coal producers and supply chain service providers. The study collected data on: ● PM10 and PM2.5 levels ● Deposited dust ● Changes in particles when coal trains pass (focus not on type of trains but effectiveness of veneering) Focus: rail corridor	Dust monitoring was conducted over a four-month program between early March and early July 2013, and provides an assessment of the impact of coal wagon veneering on ambient particle levels along the rail corridor following the commencement of coal wagon load profiling and veneering at the New Acland Mine on 2 May 2013. Monitoring was conducted at six locations along the Western and Metropolitan rail systems used to transport coal to the Port of Brisbane (Oakey, Willowburn (Toowoomba), Dinmore, Tennyson, Fairfield and Coorparoo) and one background location on a section of the Metropolitan rail system not used by coal trains (Chelmer). Partisol® Model 2025 or dichotomous Partisol® Model 2025-D sequential low-volume air samplers Model 8533 Dusttrak™ DRX Aerosol Monitor (non-compliant) to determine the five minute averaged particle measurements Note: The South Queensland Coal Health Action Network (SCAN), an alliance of community groups concerned about the health impacts of coal mining and transportation, were critical of the method used in the report, stating that, “The Western Metropolitan Coal Dust report only reports on 24 hour average concentrations at each location and makes no mention of short term 'spikes' as coal trains pass. Short-term exposure to elevated particle pollution causes adverse health impacts.” It also noted monitoring was undertaken during a wet month. (Source: http://www.lockthegate.org.au/mr_airqualityseq)	The study reported: ● PM10 and PM2.5 24-hour concentrations complied with ambient air quality objectives during the investigation period (study noted lot of rain during pre-veneering period). ● A general trend towards decreased dust deposition rates and lower levels of coal dust in the deposited dust samples was observed at most monitoring sites following the implementation of veneering. ● Changes in particle levels resulting from the passage of trains were determined to mainly be the result of re-entrained particles from surfaces within the rail corridor rather than direct emissions from trains ● Trains were found to result in little change in the 10 minute average PM10 and PM2.5 levels at 3 sites within the corridor. There also appeared to be little difference between train types. ● PM10 and PM2.5 levels at corridor site may not be rail emissions but regional urban PM - conclusion made because close correlation between rail monitors and ambient network in Brisbane ● Insoluble dust deposition rates did not exceed the trigger level for dust nuisance of 4g/m^2/30days above background levels (or 130 mg/m^2/day averaged over a 30-day period) recommended by the New Zealand Ministry for the Environment at any of the rail corridor monitoring sites during both the pre- and post-veneering monitoring periods. ● Examination indicated that mineral dust (soil and rock) was the major component, accounting for 50-90% of particles ● Coal dust was consistently detected in the

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
				deposited dust from all monitoring sites along the rail corridor used by coal trains (most around 10% - ranging from trace to 20%). At most sites, rubber dust also made up 10%.
Health hazard in our suburbs: particulate pollution along the South-East Queensland coal dust corridor May 2015 / study complete/QLD (Kane, 2015)	Michael Kane for Clean Air Queensland Alliance - community monitoring study	The study undertook preliminary particle pollution monitoring at several sites along the West Moreton rail line determine the pollution signatures from passing coal trains, both loaded and unloaded, in response to residents' long-term pollution and health concerns. Focus: rail corridor	● Nine monitoring sessions at Wynnum, Morningside, and Fairfield ● monitoring site where trains typically travel between 60-80 km/hr, free of environmental interference, close to and on downwind side of tracks ● Osiris monitors 'directly adjacent to coal rail line' and downwind to measure TSP, PM10, PM2.5, PM1 ● Stored data downloaded using AirQ32 software ● Measured ambient (5 minutes before train passed), 2 minutes during passage, 5 minutes after ● weather data collected from BOM ● pre-train arrival used as ambient value ● 8 signatures were examined for the study which represented the 'worst-case' events	● For the 8 signatures reported, loaded coal trains showed increases of 500% - 1000% over ambient levels of PM10 prior to the train passing; 500% - 900% for unloaded. The intensity of the peak varied significantly between different coal trains. Some coal trains showed no signature. ● Data gathered after rain events show little or no signature. ● Freight trains showed increases in particle pollution readings while the diesel locomotive passed, ranging between 100% and 150% of the ambient levels of PM10 prior to the train passing. ● During train passing, areas adjacent to coal corridor experience intense PM pollution between 5-9x pre-passing levels. ● Trains were assumed to be veneered, with study questioning the effectiveness of veneering in suppressing dust
Continuous monitoring in rail corridor at Cannon Hill, Qld Feb 2014 – ongoing/Queensland/ final report anticipated June 2016	Queensland Department of Environment and Heritage Protection	Continuous monitoring of PM2.5, PM10, TSP, deposited dust and meteorological on the rail corridor at Cannon Hill for comparison with guidelines Focus: rail corridor	● Monitoring 6 metres from metropolitan rail line undertaken in accordance with Australian Standard methods by Queensland Government; funded by industry ● The line is used by coal trains going to the Port of Brisbane at an average rate of 10 trains per day. ● The station also sits 300m, 600m and 1 km from three major roads. ● The PM_{10}, $PM_{2.5}$ and TSP data is available on the Queensland Government live air data site listed with other DSITIA ambient monitoring sites. Data is displayed as 24-hour averages to allow comparison with health guidelines.	The February 2016 air quality bulletin showed Cannon Hill PM_{10} and $PM_{2.5}$ 24-hour averages below EPP (Air) objectives (Department of Science, 2016). A report is due in June 2016 that will analyse five minute averaged data in relation to train spikes, i.e. particles level differences between train and no train passing.
Diesel particulate matter and coal dust from trains in the Columbia River Gorge,	Jaffe, Daniel et al (University of Washington,	For people living near rail lines: 1. What is the exposure to	● Measured particulate matter (PM1, PM2.5 and PM10), CO_2, black carbon (BC) and meteorology.	● Found a diesel PM mean value of 1.2 gm/kg fuel. This agreed well with a US EPA projection for 2013.

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
Washington State, USA Oct 2015/study complete/USA (Jaffe et al., 2015)	School of STEM, Bothell, WA USA)	particulate matter—diesel PM and coal dust? 2. Can the current and potential future exposure to PM be estimated? 3. What are the diesel PM emissions factors from the diesel trains? What fraction of diesel PM is black carbon? 4. Do coal trains emit coal dust into the air? Focus: near or in the rail corridor	• Measurements were taken during 367 train passages every 10 seconds • Measurements were made at a site between the towns of Lyle and Dallesport, Washington, between June 7–August 10, 2014. • The instruments were located about 10 meters above and 20 meters northeast of the rail line on private property with relatively few other PM sources. • Two motion–activated video cameras were used for train identification. • A TSI DustTrak DRX Aerosol Monitor was used to measure PM. • The DustTrak measurements are different to mass-based measurements; they required careful calibration against reference methods. • Only trains that could positively be identified as freight or coal were used in the analysis, so this excluded night-time trains. • Absolute enhancements were calculated by subtracting out the PM, BC and CO_2 maximums during train passage from the background concentration measured prior to each trains passage.	• Found that nearly all coal trains appeared to generate some degree of coal dust (PM2.5) based on the following evidence: ○ coal trains were associated with PM2.5 peaks that were 78% higher than freight trains. ○ Passage of diesel open coal trains resulted in almost double PM2.5 levels compared with freight trains ○ most freight trains (52%) showed a good correlation between PM2.5 and CO_2, whereas very few coal trains (16%) showed this relationship ○ The BC/PM2.5 fraction were statistically higher for freight trains compared to coal trains. ○ The PM1/PM2.5 fraction were statistically higher during passage of freight trains compared to coal trains. • Found that 4 out of the 74 coal trains (5.4%) were “Super Dusters” meaning they were responsible for large clouds of visible coal dust and high PM2.5 (50-250 ug/m^3) and PM10. This was confirmed by both the PM measurements and the video record. • In Seattle and Bellingham, there was some evidence for coal dust, but diesel PM was likely the most important PM source. This was attributed to trains going more slowly in urban areas. • Diesel PM enhancements from trains in Seattle and Bellingham were significant for homes and businesses along the rail lines. • A significant increase in the amount of rail traffic would put these locations at risk of exceeding the air quality standards.
Diesel particulate matter emission factors and air quality implications from in-service rail in Washington State, USA (Jaffe, Hof, Malashanka, Putz, Thayer, Fry, Ayres, &	Jaffe et al (2014) Atmospheric Pollution research 5 (2014) 344-351	Role of diesel in emissions and impacts for residents near rail lines	• Quantify exposure to diesel particulate matter (DPM) and airborne coal dust from trains for residents living near rail lines at 2 sites and measure the DPM and black carbon emission factors (EF).	No significant differences in average DPM EFs measured at the 2 sites Open coal trains have a significantly higher concentration of particles >1µm diameter, likely coal dust Measurement of black carbon at one site show a strong correlation with PM_1 and give an average BC/DPM ratio of 52% from diesel rail emissions

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
Pierce, 2014)				Living near rail line significantly increases $PM_{2.5}$ exposure ● For one month at Seattle site average PM2.5 near rail line 6.8µg/m3 higher compared to several background locations; as PM2.5 linear relation to diesel traffic, a 50% increase in rail traffic may put residents above the new USA AAQ standards, an annual average 12µg/m3
Air pollution emissions from diesel trains in London July 2014 / study complete / London (Fuller, Baker, Tremper, Green, Font, Priestman, Carslaw, Dajnak, & Beevers, 2014)	Environmental Research Group, King's College London	The study was undertaken to address concerns that diesel passenger trains in London may be responsible for breaches of air quality objectives for nitrogen dioxide up to 200m either side of the rail line. Focus: to improve the accuracy of modelled predictions for the Paddington mainline.	● Possibly the most comprehensive study carried out to date on pollutant emissions from rail sources on Great Britain's rail network. ● Two locations were selected: Paddington in Ealing and King's Cross in Islington to compare measured and modelled predictions to derive new NOx, NO_2, and PM emissions factors for diesel trains. ● Both monitoring sites were 10m from the tracks. ● The study compared actual levels of emissions with modelled data. ● Note: The report pointed out that although there have been many studies of air pollution from road sources there is practically no information on pollution caused by trains.	● The unexpected findings showed that rail emissions were significantly lower than from road traffic and that trains were not making a major contribution to local particulate matter and nitrogen dioxide concentrations. ● Real world measurements did not support the modelled predictions of NO_2 concentrations at 50% greater than the limit value. ● No increment in NO_2 was found when measured at a point 600m from the railway. ● The maximum hourly mean NO_2 concentration was less than the short-term EU limit value concentration of 200µ/m^3. ● Small increments were found in the concentrations of NOx and particulate matter. ● It was possible that London's traffic confounded the analysis but it was clear that diesel trains were not making a big contribution to local particulate matter and NO_2.
Particle characterisation and dust deposition studies				
Lower Hunter Dust Deposition Study - Final Report April 2016 (AECOM, 2016)	AECOM for NSW EPA	The study was designed to examine the quantity of dust deposited in the Lower Hunter and the likely sources of this deposition. This was a result of concern expressed by Lower Hunter residents over the quantities of black dust that was in their area. Focus: near or in rail	Sample sites, of which there were 12, were based on the distribution and intensity of complaints received by the EPA regarding air quality over the last 2-3 years. In addition, sites were added along the rail corridor. The sites were located at Stockton (North and South), Tighes Hill, Mayfield (East and West), Newcastle (City and East), Waratah, Islington, Tighes Hill, Hamilton, Carrington and Wickham Dust monitoring methods were categorised into three categories:	● Deposited dust annual averages ranged from 0.5 to 1.1g/m2 per month at 12 sites (notably below the EPA criterion of 4 g/m^2) ● Coal on average formed 10% of total deposited dust with a range of 0% to 25% ● Soil or rock dust comprised the greatest proportion of samples, at an average of 69% of all samples with a range of 40% to 90% Average dust deposition rate for four sites near rail corridor (one also in proximity to other industrial facilities and one to coal handling facilities were 0.8 g/m2, 0.8 g/m2, 0.9 g/m2, and

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
		corridor Note: rail corridor was defined by the EPA as being within the boundaries of the train tracks up to the fence or up to 10 metres if there is no fence.	• long-term trends: dust deposition gauges (DDGs), collected every 30 ± 2 days (AZ/NZS 3580.10.1:2003) and were analysed for insoluble solids, as content and combustible material • short-term spot checks: Petri dishes (without growth medium) at periods < 3 days - samples were analysed in a similar manner to the long-term DDGs • Identify composition: brush sampling is an active method for dust deposition collection, collecting dust samples into a clean Petri dish from suitable locations. No time dimension for the collected sample, so the source cannot be accurately specified Laboratory analysis used Standard Depositional Dust Suite, Stereomicroscopy, Scanning Electron Microscopy (SEM) and Energy Dispersive X-Ray Spectroscopy. Standards of sample handling were maintained by Chain of Custody (CoC) protocols. Meteorological data was obtained from the OEH monitor at Carrington.	1.1 g/m^{2}. Note: To ensure the views of the community were fully considered, the EPA established the Lower Hunter Dust Deposition Project Reference Group, which consists of two community, two industry, two independent technical experts and two EPA staff representatives.
Lower Hunter Particle Characterisation Study April 2016 (Hibberd et al., 2016)	CSIRO, ANSTO and OEH for NSW EPA, (and NSW Health input)	This study was initiated in 2013 to characterise the components in $PM_{2.5}$ in the Lower Hunter representative of general community exposure and the composition of $PM_{2.5-10}$ in the vicinity of the Newcastle ports This study used four monitoring sites to conduct sampling over the period of one year. • Newcastle ($PM_{2.5}$), • Beresfield ($PM_{2.5}$), • Mayfield ($PM_{2.5}$ and $PM_{2.5-10}$); and, • Stockton ($PM_{2.5}$ and $PM_{2.5-10}$)	Sampling was conducted at four sites between March 2014 and February 2015. Two sampling methods are being used: • ANSTO Aerosol Sampling Program (ASP) $PM_{2.5}$ cyclone samplers • GENT Stacked Filter Units (SFU) sampling 'coarse' ($PM_{2.5}$-PM_{10}) particles and 'fine' ($PM_{2.5}$) particles simultaneously The monitors are operated by the OEH. All samples were analysed using positive matrix factorisation (PMF) to identify source 'fingerprints'.	• Ambient air quality is generally within the 24-hour PM2.5 and PM10 standards, with occasional spikes due to industrial activities, proximity to ocean sea salt, bushfires or seasonal weather patterns. • Newcastle, Mayfield and Beresfield has similar annual average PM2.5 concentrations of 6.4-6.7ug/m3; Stockton was 9.1ug/m3, likely due to Orica's ammonium nitrate manufacturing facility. • Annual average PM2.5-10 concentrations were 8.3ug/m3 at Mayfield and 21.5ug/m3 at Stockton, the difference likely due to fresh sea salt. Composition: • The contribution of coal to PM2.5-10, as a contributor to light absorbing carbon, would be maximum 10%. Further analysis is required to confirm the coal contribution. • Coal in PM2.5 was a maximum of 4%,

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
		In addition, the study considered the results of long-term monitoring of PM10 and PM2.5 at four sites (Newcastle, Beresfield, Stockton and Wallsend) which provide an indication of the regional air quality and were used as a framework for the characterisation study. Focus: ambient and effects of port		measured as the carbon component of soil • Sea salt was a major contributor of both PM2.5 and PM2.5-10, particularly at sites close to the coast. Other sources of fine particles included sulfates, nitrates, wood smoke, soil.
Upper Hunter Valley Fine Particle Characterization Study Sept 2013/ 12 month study complete/NSW (Hibberd et al., 2013)	CSIRO and ANSTO for NSW EPA, OEH, NSW Health	Characterising the major components of $PM_{2.5}$ particles that communities in the Upper Hunter are exposed to, their relative proportions and if there are any temporal changes or patterns in $PM_{2.5}$ particulate matter. Dust characterisation was conducted at two sites, Singleton and Muswellbrook, as these are the major population centres in the Upper Hunter in close proximity to two nearby power stations and open cut mines. Focus: ambient	8 factors investigated: • wood smoke • vehicle / industry • secondary sulfate • biomass smoke • industry aged sea salt • soil (which includes fugitive coal dust) • sea salt • secondary nitrate Collected samples analysed at CSIRO and ANSTO, with researchers from both institutes evaluating and reporting on the results.	Soil (which includes a proportion of fugitive coal dust) contributed 12 ± 2% and 11 ± 1% to the total annual $PM_{2.5}$ mass for Singleton and Muswellbrook respectively. The amount of black carbon in the soil was 1% total PM2.5 at Singleton and 4% at Muswellbrook. Black carbon can have some coal as well as other sources. The primary contributing factor to the total annual $PM_{2.5}$ mass for Singleton was secondary sulfate (20 ± 2%), which includes local and regional sources of SO_2 such as power stations. For Muswellbrook, wood smoke contributed 30 ± 3% to the total annual $PM_{2.5}$ mass. The primary source of wood smoke is residential wood heaters. Note: the study conducted an analysis of the characterisation of the samples, but the source of the particles was not determined
Remote measurement of diesel locomotive emission factors and particle size distributions 2013/Queensland University of Technology/Queensland (Johnson, Lau, Thomas,	Johnson, G et al	There are limited studies measuring trackside emissions from trains to evaluate the air quality impacts associated with locomotive combustion of diesel. Examined emission factors	Sampled diesel train exhaust emissions primarily from loaded coal trains (60 of 73 sampled) 9m from the rail line near Moreton Bay enroute to the Port of Brisbane. The study developed emission factors for very large freight trains for five variables: particle	Amongst other findings, the study concluded that particle mass emission factor $EF(PM_{2.5})$ were strongly correlated with SO_2. Thus, it is possible that SO_2 could be used as a marker for in future rail corridor studies.

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
Juwono, Kitchen, & Morawska, 2013)		and particle size distribution for mainly coal trains in a pristine environment in Queensland	number, PM2.5 mass fraction, SO2, NOx, and CO2 to estimate emissions based on fuel use.	While the results may not be directly applicable to NSW trains in the Hunter, the direct measurement methods used may be of interest for future studies to help factor out the diesel contribution to these specific pollutants.
Bloomfield Colliery Annual Environmental Management Report 2014 2014/ in relation to ongoing dust deposition monitoring (The Bloomfield Group, 2014)	Bloomfield Collieries Pty Ltd	Ongoing monitoring of deposited dust near mine	Total of 10 dust deposition gauges and 2 high volume air samplers (HVOL) in and around the mine, with one site adjacent to the main north rail line (since 1997). Note: the Review is aware that other operators also undertake similar ongoing dust monitoring, which it will seek information on for the next phase of the Review.	• Results from January to December 2014 showed insoluble solids to be between 0.7 and 3.0 g/m^2/month. EPA guidelines are 4 g/m^2/month • Composition of dust not determine • Dust deposition monthly results for 2014 at the site near the rail line were similar to those for a site near the New England highway (note: exact distances from highway and rail line not known), with the highway site recording one month of exceedances (6 4 g/m^2/month for November 2014)
T4 Project Environmental Assessment, Volume 1, Chapter 12 Air Quality 2012 Feb 2012 (study by PWCS from 2006 to 2010)/NSW (EMGA Mitchell McLennan, 2012)	EMGA Mitchell McLennan for Port Waratah Coal Services (PWCS)	This chapter of the coal export terminal 4 (T4) Project Environmental Assessment (EA) assesses the existing ambient air quality and the anticipated air quality impacts due to the T4 project. Focus: PWCS coal export terminal	The T4 Project EA reported that, in response to community enquiries, PWCS commissioned several microscopic examinations of dust samples in the local area from 2006 to 2010. The sampling was undertaken at Stockton and Fern Bay which are both close to the Kooragang coal terminal at 1.8km away 1.9km away respectively.	An analysis of dust deposition samples collected from Stockton and Fern Bay found that the contribution of coal particles to annual dust deposition ranged from 5% to 16%. Note: the Review was unable to locate the actual dust examination (2006 - 2010) report
Tennyson Dust Monitoring Investigation September to October 2012 Dec 2012 / study complete/QLD (DSITIA, 2012)	Queensland Department of Science, Information Technology, Innovation and the Arts (DSITIA)	Particulate levels (PM_{10}) and dust deposition in or near the corridor; contribution of coal particles in deposited dust Focus: rail corridor	Measured PM10 to compare against health guidelines, deposited dust for nuisance, and component of coal in dust. The study measured PM_{10} (one site in rail corridor ~6m from tracks) and deposited dust at three different locations (approx. 6, 20 and 300 m from track). Wind speed and direction was also recorded. The report noted there was little rainfall during the study period. **Air sampling:** Partisol Model 2025 sequential low-volume air	• Study found PM10 levels at the Tennyson station site did not exceed the Queensland Environmental Protection (Air) Policy 2008 (EPP Air) 24-hour average air quality objective (50 µg/m3) during the study period. Average was 26.6 µg/m3. The report noted that on a day with only four freight trains passing, a reading of 19.0µg/m3 may be indicative of the typical background level in the Tennyson community in the absence of train and motor vehicle sources. • Insoluble dust deposition did not exceed the trigger level for nuisance dust based on the

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
			sampler (AS/NZS 3580.9.10.2006) at Tennyson station measuring daily 24-hour average PM10, Model 8533 DustTrak DRX Aerosol (non-compliant) to determine the five minute averaged particle measurements (laser based method, not mass based like the Partisol) **Dust deposition**: In accordance with the Australian standard for deposited matter (AS/NZS 3580.10.1.2003)	New Zealand Ministry for the Environment standard, although it was noted that the deposited dust may be highly visible to residents. Trigger levels were 4 g/m2 /30 days or 130 mg/m2 /day. • Mineral dust (crushed soil and rock particles) was the primary depositional component, with coal dust accounting for 10-20% of the deposited samples at each of the sites. • On average, particles less than 20µm increase by an average of 5 µg/m3 due to passing trains, with loaded coal trains having the greatest impact. • Concluded that trains, irrespective of type, increased particulate matter in the air. As the major depositional component was soil and rock dust, the study concluded that the re-entrainment of surface dust as a result of the train passing was the primary contributor to an increase in airborne particulate matter.
Testing source of emissions (e.g. wind tunnel studies to determine dust lift off) / examining mitigation techniques				
Pollution Reduction Program 5.0 Investigation of Coal Loss from Rail Wagons on the ARTC Network March 2016/ summary report The ARTC must provide a report summarising the findings of the assessments to the EPA by 1st March 2016. Note: full report not publically released. (ARTC, 2016)	ARTC for the NSW EPA	Laying drop sheets on track to capture any potential spilled coal during rail transit to identify quantities and source of spill from the train. Focus: rail corridor	The ARTC undertook an initial program to investigate coal deposition on departure roads and to assess the effectiveness of removing coal deposition with vacuum equipment. Rate of deposition was tested by placing mats at four departure track sites known to receive high rates of deposition Effectiveness of vacuuming deposition on ballast at 3 turnouts and one 100m straight section Complementary to this, the EPA is in discussion with rolling stock operators, licensed coal loading premises and coal terminals regarding their existing management of coal transport including controls and measures in place to prevent loss of coal from wagons to the rail formation.	Rates of deposition are highly variable; particle size was predominantly within gravel classification of 2-60 mm. At turnout larger particles were found in 'cobble' size of >60mm. Industrial vacuuming equipment partially effective in removing deposited dust from track; main benefit for operational reliability of track; time consuming and expensive Vacuuming is more beneficial at turnouts and cross overs, but on longer track lengths it would impact daily movements and does not address the source of the deposition.
Opacity monitoring investigation	ARTC	Investigate coal loss from surface of open wagons –	Investigating plans to monitor the rail network to measure opacity across the top of coal wagons.	Study and results are pending

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
Pending/NSW		validate wind tunnel testing	This can indicate dust emissions from the open surfaces and verify the effectiveness of controls.	
Dust Emission Investigation of 6 Xstrata Coal Samples Report #7761-2 September 2012/ report complete/ NSW (Tunra Bulk Solids, 2012) Note: a second wind tunnel testing program was undertaken by NSW industry, with results not yet publically available	Tunra Bulk Solids Handling Research Associates (Newcastle Institute for Energy and Resources) for Xstrata Coal	Study to measure the Dust Extinction Moisture (DEM) and wind tunnel lift off characteristics for six types of Hunter Valley coal.	The DEM was determined using a procedure set down in Australian Standard AS-4156.6-2000. Wind tunnel: material greater than 6.3mm was removed (larger sizes less likely to lift off). The sample screening procedure was adopted from Australian Standard AS-4156.6-2000. The test program involved testing of each coal sample under six scenarios: 1. Dust lift-off at fines production total moisture (TM) level on a normal day 2. Dust lift-off at fines production TM level with pre-drying 3. Dust lift-off at DEM level on a normal day 4. Dust lift-off at DEM level with pre-drying 5. Dust lift-off at DEM level with water only suppression and pre-drying 6. Dust lift-off at DEM level with veneering suppression and pre-drying	• The DEM values for -6.3mm size fraction of tested coal were 4.2% (Tahmoor), 5.9% (Bulga), 7.2% (Rav UG), 7.3% (Liddell), 8.8% (Ulan), and 11.6% (Mangoola). (sample name) • The average full size production total moisture for the six samples was 8.4% (Tahmoor), 10.0% (Bulga), 8.0% (Rav UG), 10.0% (Liddell), 10.5% (Ulan) and 13.0% (Mangoola). • The production moistures are above DEM which indicates that unless significant surface drying occurs, potential dust lift off during railway transport at those moisture levels is expected to be minimal. • The estimated fines total moisture is 1.7-3.4 times the DEM of the coal samples • Wind tunnel testing: there was no measurable lift off for scenarios one, two, five and six except for a small amount from the Ulan sample under scenario five (which due to a longer travel distance was tested for 8 hours instead of 4). • For all coal samples, dust emissions were recorded for scenarios 3 and 4 due to pre-drying causing an increase in dust emissions whilst the samples were exposed in the wind tunnel. Overall, significant dust emissions were recorded for the Bulga and Tahmoor samples (in excess of 100g during exposure) whereas the Rav UG, Mangoola, Ulan and Liddell samples recorded dust lift off of 50g or less. • No lift off was observed for chemically veneered samples; dust lift off was observed for all samples when tested at DEM with no surface application
Duralie Extension Project, Study of Dust Emissions from Rail Transport	Katestone Environmental Pty Ltd for Duralie	Katestone Environmental and Introspec Consulting were commissioned by	The study included the following: • Site inspection and review of the Duralie Extension Project	The findings were: • Of 527 complaints received by Gloucester Coal in relation to the Duralie and Stratford

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
Feb 2012 / study complete/NSW (Katestone Environmental Pty Ltd, 2012)	Coal Pty Ltd	Duralie Coal Pty Ltd (NSW) to prepare a study of dust emissions from rail transport between Duralie and Stratford coal mines (20km). Focus: rail corridor	● Review of the history of complaints relating to dust emissions from laden coal trains ● Identification of the significance of dust emissions from laden coal trains ● Review of literature relating to dust emissions from laden trains ● Laboratory wind tunnel testing of Duralie coal to investigate dustiness conducted by TUNRA Bulk Solids at the University of Newcastle. ● Cost benefit analysis of potential dust controls ● Recommendations for control of emissions from laden coal trains Note: A detailed peer review of the air quality assessment of the Duralie Extension Project was conducted by Heggies Australia with particular attention given to the aspects relating to railing coal between the Duralie and Stratford Coal Mines. The Heggies review concluded that quantification of dust emissions from wagons carrying coal was consistent with contemporary practice and would provide a conservative estimate of potential emissions of coal dust (e.g. the emission rate was consistent with the QR Environmental Evaluation [Section 6.1]).	Coal Mines from 2002 to 2011, two were possibly related to dust issues associated with the railing of coal between the mines. ● The coal surface of the wagons of laden coal trains was found to be the most significant source of rail generated dust in the case of the Duralie Extension Project. Maximum 24 hour concentrations of PM10 at 20m from the rail centre line were predicted to be approximately 4µg/m^3. In comparison, the 24hr criteria for PM10 is 50µg/m^3. ● Dust extinction moisture level for Clareval Coking ROM coal was determined to be 4.1%. (For comparison, the typical minimum moisture content of NSW coals is 9-11%) ● The additional cost of chemical surface veneer above that for the application of water alone was estimated to be $0.05 per tonne of coal. ● The recommended method for control of emissions from wagons was continued use of the two-stage water spray system at the rail loadout facility which was reported to be around 98% effective in controlling dust lift-off, reducing lift-off to almost nil. ● Since veneering was found to be only slightly more effective (96-100%) than water, it was not recommended.
Coal Leakage from Kwik-Drop Doors - Coal Loss Management Project July 2009 / study complete/QLD (Aurecon Hatch, 2009)	Aurecon Hatch (formerly Connell Hatch) for Queensland Rail	To provide a more reliable estimate of coal leakage from Kwik-Drop doors. Focus: rail corridor	Used an innovative Door Loss Measurement Mechanism (DLMM) to capture losses for both loaded and unloaded coal trains through the Kwik-Drop doors during a week-long trial in Goonyella and Blackwater. The DLMM design incorporated four overlapping trays housed in a frame attached to the bottom of the wagon. Outlined potential errors: ● mine offset - losses that occur at the mine site, such as loading practices. ● ploughing - this was suggested to be a result of the larger particles (>9.5 mm) that were present on the sampling trays - study	Goonyella ● Average coal collected per tray was 143.6 g, which equates to 574.4 g per door set ● When extrapolated to the average train size in the Goonyella system, which has 440 door sets, the average loss per train is 253 kg. ● The average number of trains per week is 144.7, and this would result in an annual loss of 1900t, or 0.0022% of the yearly tonnage Blackwater ● Average coal collected per tray was 209.8 g, which equates to 839.2 g per door set

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
			concluding that ploughing at the ports during unloading would be the most logical source of these particles Note: The study identified variables that may influence coal loss through the doors that include (but are not limited to): ● Coal type and rank ● Meteorological conditions ● Moisture content ● Washed/unwashed coal ● Proportion of fines ● Longitudinal travel forces ● Wagon design (door design and wagon stiffness) ● Track geometry and condition ● Wagon condition and maintenance	● when extrapolated to the average train size in the Blackwater system, which has 320 door sets, the average loss per train is 276 kg. ● The average number of trains per week is 126.4, and this would result in an annual loss of 1750t, or 0.0034% of the yearly tonnage There was no significant correlation between coal loss and door clearance measurements, nor was there any increasing trend between these variables. Determined that due to 83% of the wagons following the same trend in losses, that coal loss is dependent on the source of the coal. However, indicated that two trials that serviced the same mine showed different results that indicate that there could be factors other than coal type alone that may influence the quantity lost. Concluded that two-thirds of all losses are particles < 2 mm. As the nominal design clearance of the wagon doors is between 2-3 mm (largest was 8 mm), it is expected that door clearance does not have a significant impact on the particle size distribution of coal loss through the Kwik-Drop doors.
Managing Dust Emissions from Mine to Port Abstract in ACARP Matters, 24 June 2012 (ACARP, 2012)	John Planner at Introspec Consulting for ACARP	Review of current best practice in dust control techniques across the coal industry, from mine to port	Note: Review examined abstract.	Abstract primarily focused conclusions on controlling moisture content of coal. Suggested measures related to coal transport include: ● keeping coal above its DEM level during transport and handling ● applying a veneer chemical treatment to coal surface for long distance rail travel ● install moisture monitoring equipment at rail discharge facilities ● using water sprays at rail discharge facilities when needed ● establish minimum discharge height for stacking Abstract noted companies should conduct DEM

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
				testing on each product and continually monitor actual moisture at sampling points along chain.
Reduction of carry-back and coal spillage in rail transport Dec 2008 / study complete/QLD (ACARP, 2015)	ACARP Project Number C15071 Einicke, G, Hargrave, C, Haustein, K et al, CSIRO	Consider carry-back coal to mines and develop a carry-back detection system which automatically generates alerts when volumes exceed threshold	Note: Review examined abstract only.	The abstract noted: ● Carry-back coal can cause spillage and cross contamination. ● Spillage can contaminate the ballast and possibly lead to derailments and excess coal can jam doors ● Industry surveys showed from March to Aug 2007, carry-back was 0.36 tonnes per wagon and for two rainy months during the period, were closer to 0.93 tonnes per wagon, or one wagon per train. ● The carry-back costs the industry between $42M and $102 M annually ● suggests installing automatic vibrators at ports
BNSF Super Trial 2010 / study complete/USA (BNSF, 2010)	BNSF and Union Pacific Railroad	Phase 1 - tested the effectiveness of seven different chemical agents in suppressing coal dust emissions from loaded trains Phase 2 to test railcar compaction and shaping prototype - to apply physical forces to a loaded railcar to drive coal fines away from the open top of a railcar, displacing coal dust particles from the upper profile of a loaded car, which is most vulnerable to winds during transport. Focus: rail corridor	Trackside Monitors - weather/aerosol monitors Passive Dust Collectors on wagons Portable weather stations on wagons Tested 1,633 trains; half the trains were treated - some treated before coal loaded, some topically on the load	● Phase 1 - Results of passive dust collector tests on 115 treated trains showed that topical treatment reduced emissions 75-93%; body treatment to the coal did not significantly reduce emissions. ● The veneering requires proper application to increase effectiveness ● Results from Phase 2 not located. Note: BNSF, the below track operator, noted coal on tracks was a significant operational issue and now requires operators to reduce emissions from wagon surface by 85% from untreated levels through Coal Profiling Rule and veneering.
Wind tunnel studies of coal dust release from train wagons 2004 / study complete/Portugal	Ferreira A D, Vaz P A Journal of Wind Engineering and Industrial Aerodynamics	Ferreira and Vaz (2004) used scale model trains in a wind tunnel to show that covering coal wagons reduced dust emissions by more than 80 percent.	This paper presents a wind tunnel study to assess the coal dust released due to aeolian erosion from wagons equipped with two different shelter cover systems. A 1:25 scale model was used, comprising one locomotive and four train wagons with a 3.55 m	● Several tests were conducted for different train configurations, and two initial load levels. ● The study conducted measurement of TSP emissions from coal wagons over a simulated 350km journey, and found that a

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
(Ferreira & Vaz, 2004)		Focus: rail corridor	maximum length.	60t semi-covered wagon would lose approximately 0.0007% of its load with an undisturbed flow velocity of 13.4 m/s (48.2km/hr). ● The use of the semi-cover system, despite the existence of a 1m wide gap along the upper part of the wagon, significantly reduced the amount of dust released. ● Compared to the no-cover situation, the semi-cover reduced the dust amount released more than 80% for the full-load situation. ● The results for the last two wagons showed considerably larger quantities being eroded, suggesting the benefit of covering the last two cars in a unit train during train transportation of granular material. ● However, the authors noted that this suggestion needed further experiments to be fully supported.
Full-scale measurements for evaluation of coal dust release from train wagons with two different shelter covers 2003 / study complete/Portugal (Ferreira et al., 2003)	Ferreira AD, Viegas DX and Sousa ACM Journal of Wind Engineering and Industrial Aerodynamics	Ferreira et al. (2003) conducted full-scale tests on coal wagons in Portugal to evaluate the effectiveness of two different types of partial covers. Focus: rail corridor	Coal dust was collected using special dust collectors mounted on top of the wagon whilst the train travelled from a port to a power station. The average train speed for a 350km transit was estimated to be between 55 and 60km/hr. Train speeds reached a peak of 65km/hr to 85km/hr. Connell Hatch in the 2008 Environmental Evaluation report (2008) considered that the overall train speeds, transport distances and climatic conditions during the sampling were comparable to conditions in Queensland.	● An extensive literature search conducted by the authors revealed that there was an apparent lack of reliable quantitative information based on studies involving full-scale, or even small-scale, studies devoted to the problem of ''fugitive'' dust releases during the process of long-distance transportation using train wagons. ● Ferreira observed that coal cars equipped with even partial covers emitted much less coal dust than those without covers. The wagons tested had partial covers with a gap of 1m. ● The paper concluded that fugitive dust emissions amounted to less than 0.001% of the 60 tons net load of coal for partly covered wagons, using a 95% confidence interval, over a particular 350 km run.
Other related work by NSW EPA				
Environmental Compliance Report - Compliance Audit of coal train loading and unloading facilities	NSW EPA	NSW EPA completed a compliance audit program of eleven coal train loading and four unloading facilities in NSW. Ten of the coal	Audit and inspections Note: The EPA has undertaken follow-up inspections of all premises that had non-compliances. Considerable progress had been	● A number of non-compliances found ● Issues with the loading of the wagons – 10/11 (one unknown) non compliances with EPL condition “carrying out train loading activities in a manner which minimises or

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
Dec 2014 / study complete/NSW (NSW EPA, 2014a)		loading facilities transport coal to the Port of Newcastle and three unloading facilities are located in the Newcastle area. Focus: rail loading and unloading facilities	made at most premises to address the issues raised by the audit. These changes include installation of additional loading infrastructure and monitoring equipment, updated procedures and enhanced training of staff. The inspection program is targeting parasitic coal prior to arrival and at departure from facilities, dust emissions and ploughing – coal extending above the railway lines in the discharge hoppers and being caught up in the wagon undercarriages. To identify and implement actions to reduce parasitic coal on coal wagons leaving the coal handling facility, the coal terminals at Newcastle are undertaking a wagon monitoring and reporting environmental improvement program as part of their licence conditions. In addition, the EPA carried out an inspection program on a number of coal loading and unloading facilities in the Illawarra in November/December 2015.	prevents coal spills and dust emissions from the tops of wagons during rail transport" ● Unloading facilities rated better, with some 'unknown' compliance status around carrying out unloading activities to minimise or prevent small amounts of coal dust emissions from the interiors of empty wagons.
Review of regulation of 'railway systems activities' under the Protection of the Environment Act 1997 Sept 2014 - position paper released (NSW EPA, 2014b)	NSW EPA	The objective of the review is to determine the most effective framework for regulating the impacts of rail construction and operational rail activities on the NSW environment and community. Focus: rail corridor	The EPA is proposing an amendment to 'railway systems activities' under the POEO Act to implement the preferred alternative regulatory framework. EPA is working with the Parliamentary Counsel's Office to finalise a draft amendment regulation. This draft is expected to be placed on exhibition on the EPA website in late November/early December 2015. Should the amendment regulation be passed, licensing of rolling stock operators as a separate scheduled activity would commence in end 2016/ early 2017.	The position paper outlined 10 options with the preferred option to licence both the above and below rail operators.
Diesel Locomotive Emissions Upgrade Kit Demonstration Project NSW (ABMARC, undated)	ABMARC for NSW EPA	Tested the impacts of retrofitting emission upgrade kits to two in-service diesel locomotives on exhaust emissions, fuel efficiency and noise.	The EPA worked with rolling stock operator Pacific National to test the impacts of installing emission upgrade kits on exhaust emissions, fuel efficiency and noise on two Electromotive Diesel (EMD) locomotives using US Tier 0+ emission standards (standards applying to locomotives originally manufactured from 1973) (DieselNet,	● Findings post kit-fitting included significant reductions of emissions including particulate matter (weighted results ranging from 59% to 66% g/kWhr), oxides of nitrogen (weighted results ranging from a 30% to 44% g/kWhr reduction), carbon monoxide and total hydrocarbons but a concurrent

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
			2016; US EPA, 2016a).	increase in carbon dioxide and decrease in fuel efficiency • The report suggests further testing is warranted given the kit manufacturing specifications indicate fuel consumption improvement in the order of 2-5%. The EPA reports that further testing of emissions and fuel consumption using different engine settings is being undertaken, with results anticipated to be released later in 2016
Locomotive Emissions Project: Scoping Study of Potential Measures to Reduce Emissions from New and In-Service Locomotives in NSW and Australia March 2013 scoping study – Other work in progress /NSW (ENVIRON, 2013)	Prepared for: NSW EPA by: ENVIRON Australia Pty Ltd	NSW EPA undertaking a joint project with a large NSW rail operator to determine potential emissions reductions and fuel efficiency from diesel engines by installation of emissions upgrade kits on older diesel locomotives at scheduled rebuilds. Focus: rail corridor	Performed cost effectiveness studies and annual health benefits ($) for different options. Health costs were estimated overall for rural and urban areas using emissions factors and fuel usage.	The largest health benefits were potentially from upgrading old and having new locos meet Tier 4 standards. Annual health costs in Australia from diesel locomotive emission exposure estimated at $65.6 million.
Development of industry environment standard Work in progress/ outcomes pending	Rail Industry Safety and Standards Board (RISSB) with NSW EPA participation	The Rail Industry Safety and Standards Board (RISSB) is working towards an Industry Rail Environment Standard, covering air and noise emissions. Focus: rail corridor and broader	RISSB are developing a suite of 178 Australian Railway Standards over the next 10 years, which will gradually replace the Manual content	Outcomes pending
Air pollution (including particulate matter) and human health generally (non –coal or –rail specific)				
Review of the health impacts of emission sources, types and levels of particulate matter air pollution in ambient air in NSW NSW/2015 (Hime et al., 2015)	Hime, Cowie and Marks. Woolcock Institute Produced for the NSW EPA and NSW Ministry of Health	Focus on health effects of exposure to outdoor (ambient) particulate matter air pollution, specifically for source-specific PM relevant to the NSW population (e.g. vehicles, bushfires, coal dust, etc.)	Literature review – majority of the studies epidemiological studies. Literature on health effects of exposure to course PM (PM2.5-10), fine PM2.5, ultrafine PM.1, trace metals, organic molecules, sulphates, nitrates in PM	• Strong and consistent evidence of ambient PM2.5 and PM10 has impacts on mortality, respiratory and cardiovascular health • There is limited evidence to support that coal dust is more hazardous to health in exposed communities that PM from other sources. • The evidence to link health effects to PM from combustion related emissions is stronger

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
				• While urban levels of PM in NSW are low by world standards, the levels that exist will have measurable adverse health impacts, particularly in vulnerable populations. • Methods to determine the health impact from source-specific PM is evolving.
Ambient Particulate Matter Air Pollution Exposure and Mortality in the NIH-AARP Diet and Health Cohort USA/2015 (Thurston et al., 2015)	Thurston et al (2015) Environ Health Persp DOI: 10.1289/ ehp. 1509676	Test relationship between long term PM 2.5 exposure and death risk – rationale p.5: Few large scale cohort studies; PM pollution levels have been declining – need to test if past studies done when levels higher still replicable	Individual data (participants aged 50-71 living in 6 states and 2 cities identified through NIH-AARP data linked with Department of Social Security death data sets) linked with estimate of residence outdoor annual $PM_{2.5}$ exposures (using data from the US EPA nationwide Air Quality System when census tract PM2.5 data were available) for the period 2000-2009; using Cox proportional hazards models for Hazard Ratio (HR) estimates per $10 \mu g/m^3$ exposure	PM 2.5 Significantly associated with total mortality (HR=1.03, 95% CI= 1.00, 1.05) and CVD mortality (HR=1.10, 95% CI=1.05,1.15) Association with respiratory mortality not statistically significant (HR=1.05, 95% CI= 0.98,1.13) – significant association only among never smokers
Association of Mortality with long-term exposures to fine and ultrafine particles, species and sources: results from the California Teachers Study Cohort USA/2015 (Ostro et al., 2015)	Ostro et al (2015) Environmental Health perspectives; 2015; 123(6): 549-556	Effects of chronic exposure to ultrafine (UF) particles	For period 2001-2007, >100,000 women from the prospective CA Teachers Study linked to exposure data at residential level using a chemical transport model that computed pollution concentrations from >900 sources in Ca at 4km spatial scale; using a Cox proportional hazard model to estimate pollution (constituents in $PM_{2.5}$ and UF) and all-cause, CVD, IHD and respiratory mortality	Significant positive association between IHD mortality and both fine and ultrafine particles Exposure model effectively measured local exposures and assisted examination of relative toxicity of particles
Effect of time-activity adjustment on exposure assessment for traffic-related ultrafine particles (Lane et al., 2015)	Lane, K et al Journal of Exposure Science and Environ Epidemiology	Evaluate effects of time-activity adjustment on exposure assessment (of ultrafine particles) and associations with blood biomarkers for a group living near a major highway	A regression model based on mobile monitoring and spatial and temporal variables was used to generate hourly ambient residential particle number concentration for 140 participants. The authors noted a need for studies that directly test association of chronic UFP exposure with cardiovascular disease risk with no known studies that have reported relationships between chronic exposure to UFP and measures of cardiovascular health risk.	• Lower exposures were predicted for participants who spent less time at home • Authors found associations with more time at home with high sensitivity C-reactive protein and Interleukin-6, although exposure-response functions were non-monotonic. • The findings suggest that time-activity adjustment improves exposure assessment for air pollutants that vary greatly in space and time (e.g. ultrafine particles).
TP03: Health Effects of Traffic-Related Air Pollution NSW/2014 (ACTAQ, 2014b)	NSW Health	Expert paper provided to the NSW Advisory Committee on Tunnel Air Quality	Review of current literature	There is very good evidence that exposure to $PM_{2.5}$ causes cardiovascular disease, respiratory disease and mortality. Associations have also been observed between $PM_{2.5}$ exposure and reproductive and development effects such as

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
				low birth weight (Pedersen et al 2013). Exposure to PM_{10} is associated with cardiovascular disease, respiratory disease and mortality. Because PM_{10} includes $PM_{2.5}$, there is some uncertainty about how much of the observed effect is due to $PM_{2.5}$ and how much is due to the larger particle fraction ($PM_{10-2.5}$). Ultrafine particles (UFPs) of <0.1µ
Review of evidence on health aspects of air pollution- REVIHAAP Project Technical Report Europe/2013 (WHO, 2013b)	World Health Organisation Regional Office for Europe, Denmark	Review of scientific literature since 2005	Context for project: Directive 2008/50/EC of the European Parliament and of the Council of 21/5/08 on ambient air quality and cleaner air for Europe: recital 2 "emissions of harmful pollutants should be avoided, prevented or reduced and appropriate objectives set for AAQ taking into account relevant WHO standards, guidelines and programmes"	Particles in PM_{10} size have effects independent of $PM_{2.5}$ Increasing evidence of health effects of coarse PM $_{2.5-10}$ Increased mortality, decreased life expectancy Cardiovascular and respiratory effects (generally impacting already existing disease Cancer Central nervous system effects Developmental effects
Air pollution and lung cancer incidence in 17 European cohorts: prospective analyses from the European Study of Cohorts for Air Pollutants (ESCAPE) Europe/2013 (Raaschou-Nielsen et al., 2013)	Raaschou-Nielsen et al (2013) Lancet Oncol 2013; 14:813-22	Assess long term exposure to ambient air pollution and lung cancer incidence	Prospective analyses using data from 17 cohort studies in 9 European countries; air pollution assessed by land use regression models for PM_{10}; $PM_{2.5}$; $PM_{2.5-10}$ (coarse), soot, nitrogen oxides and two traffic indicators. Cox regression models used with adjustment for confounders for cohort-specific analyses and random effects for meta-analyses	PM air pollution contributes to lung cancer incidence in Europe. Meta-analyses showed a statistically significant association between risk for lung cancer and PM – for every increase in particulate matter pollution of 10µg/m^3 there was a corresponding immediate increase in the chance of being diagnosed with lung cancer of 22% (PM_{10}) and 40% ($PM_{2.5}$) PM_{10} HR 1.22 [95% CI 1.03-1.45] per 10µg/m$^{3;}$ PM $_{2.5}$ HR 1.18 (0.96-1.46) per 5µg/ m3; the same increments were associated with adenocarcinomas of the lung. An increase of road traffic of 4,000 vehicle-km/ day within 100 m of the residence was associated with an HR for lung cancer of 1.09

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
				(0.99-1.21). No association shown between lung cancer and nitrogen oxides concentration or traffic intensity on the nearest street per 5,000 vehicles per day
Air Pollution and Cancer 2013 (Straif, Cohen, & Samet, 2013)	International Agency for Research on Cancer (IARC) Scientific Publication No. 161; Straif, Cohen and Samet (eds.)		One of a series of monographs on air pollution	Evaluates carcinogenicity but doesn't specifically quantify risk at individual or population level. Urban air pollution worldwide as measured by concentration of PM causes 5% all mortality attributable to cancers of trachea, bronchus and lung (p.13)
The carcinogenicity of outdoor air pollution (Loomis, Grosse, Lauby-Secretan, El Ghissassi, Bouvard, & Tallaa, 2013)	Loomis et al (2013) The Lancet 2013; 14: 1262-1263	24 experts from 11 countries assessed evidence for carcinogenicity of outdoor air pollution – last in a series		The IARC Working Group unanimously classified outdoor air pollution and particulate matter from outdoor air pollution as carcinogenic to humans (IARC Group 1), based on sufficient evidence of carcinogenicity in humans and experimental animals and strong mechanistic evidence
A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010 2012 (Lim et al., 2012)	Lim et al Lancet 2012; 380: 2224–2260		Limits of previous studies' ability to measure additional increments of risk above a concentration of 50µg/m3 for PM2.5 due to narrow range of ambient PM pollution levels reported in epidemiological studies; study addresses by use of an integrated exposure–response curve which allows risk estimates across a range of concentrations; but doesn't address how different sources of PM interact in terms of effects and overlapping exposures	PM2.5 contributed to 3.2 million premature deaths worldwide, due largely to CVD and 223,000 deaths from lung cancer. Outdoor PM air pollution 9th ranked risk in world (4th in east Asia, 26th Australasia) based on disability adjusted life years (DALYs) Area-specific studies required as GBD can mask significant differences
Risk of Nonaccidental and Cardiovascular Mortality in Relation to Long-term Exposure to Low Concentrations of Fine Particulate Matter: A Canadian National Level cohort Study	Crouse et al Environmental Health perspectives 2012; 120(5): 708-714	First national-level study in Canada of risk of mortality associated with long term exposure to fine particulate matter ($PM_{2.5}$)	Assigned estimates of PM 2.5 exposure derived from satellite observation to a cohort of 2.1million non-immigrant adults (20% of the Canadian population required to provide census data in 1991) and linked to records of deaths in period 1991-2001. Hazard ratios and confidence intervals adjusted for available individual level and contextual covariates using standard Cox proportional survival models and nested, spatial	Mortality associated with long term exposure to $PM_{2.5}$. Associations observed with exposures to PM 2.5 at concentrations predominantly lower than those previously reported (mean 8.7µg/m^3; interquartile range 6.2 µg/m^3) HR 1.15 (95% CI: 1.13-1.16) from non-accidental causes and 1.31 (95% CI 1.27-1.35) from IHD

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
2012 (Crouse et al., 2012)			random effects survival models	for each 10µg/m^3 increase in concentration of $PM_{2.5}$
Diesel engine exhaust carcinogenic 2012 (IARC, 2012)	IARC Press Release No. 213, 12 June 2012			Diesel exhaust emissions classified as carcinogenic to humans "*based on sufficient evidence that exposure is associated with an increased risk for lung cancer"*
Attributing health effects to apportioned components and sources of particulate matter: an evaluation of collective results (Stanek, Sachs, Dutton, & Dubois, 2011)	Stanek et al Atmospheric Environment	Considered health effects based on the composition of PM exposure rather than PM mass exposure alone	Review of published literature that focuses on short term exposure to PM; includes at least 5 components of PM; grouped the components into factors or sources; used quantitative methods to examine the relationship between health effects and the factor/sources. Examined if specific sources/groups were linked to adverse health outcomes.	• Studies suggest that PM2.5 is associated with cardiovascular effects from crustal or combustion sources, but the relationships are not consistent • Fewer studies examined the associations between respiratory health effects • Health effects have been linked to multiple groups/sources of PM, but collective evidence has not yet isolated factors/sources that link to specific health outcomes.
Traffic-related air pollution: a critical review of the literature on emissions, exposure and health effects 2010 (Health Effects Institute Panel, 2010)	Health Effects Institute HEI Panel		Comprehensive literature review on emissions, exposure and health effects of traffic-related air pollution. The panel noted a preference for a hybrid approach in assigning exposure to primary traffic-related pollution – use of surrogates and proximity model.	• The panel identified 300 to 500 m from a major road as most highly affected by traffic emissions, with the exposure zone more broadly between 50 and 1500 m depending upon pollutant and meteorological conditions • The panel found sufficient evidence to support a causal relationship between exposure to traffic-related air pollution and exacerbation of asthma. It found "*suggestive evidence of a causal relationship with onset of childhood asthma, non-asthma respiratory symptoms, impaired lung function, total and cardiovascular mortality, and cardiovascular morbidity, although the data are not sufficient to fully support causality*".
Air Quality and Health 2010	Kunzli et al European Respiratory			Challenges of understanding interaction air pollution and health include multiple sources and mixture of pollutants; dynamic nature of process; exposure variation; significance of even low

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
(Kunzli et al., 2010)	Society			levels; cause and effect not always clear; mixture of factors influencing health
Particulate Matter Air Pollution and Cardiovascular Disease: An Update to the Scientific Statement From the American Heart Association 2010 (Brook et al., 2010)	Brook et al Circulation 2010; American Heart Association	Evaluate and update statement on scientific evidence for link between PM exposure and CVD		A range of studies provide additional persuasive evidence of link between present levels of air pollutants and cardiovascular morbidity and mortality. Short-term exposure to $PM_{2.5}$ over a period of a few hours to weeks can trigger CVD-related mortality and nonfatal events, including myocardial ischemia and MIs, heart failure, arrhythmias, and strokes. Increase risk for acute $PM_{2.5}$ associated CV morbidity & mortality principally among susceptible but not necessarily critically ill, some studies indicating, older people, those with pre-existing coronary artery disease and possibly diabetes. Most studies support the idea that longer-term $PM_{2.5}$ exposures increase the risk for cardiovascular mortality to an even greater extent than short-term exposures. The $PM_{2.5}$ concentration–cardiovascular risk relationships for both short- and long-term exposures extend below 15µg/m^3 (the 2006 annual NAAQS level) without a discernible "safe" threshold.
Integrated Science Assessment for Particulate Matter 2009 (US EPA, 2009)	US EPA National Center for Environmental Assessment-RTP Division US EPA 2009; EPA/600/R-08/139F	Evaluation of the scientific literature on human health and PM exposure; part of the EPA's periodic review of the US national AAQ standards	Findings presented in terms of: Causality (5 level hierarchy- causal, likely, suggestive, inadequate to infer, not likely) Quantitative relationships (risks): Concentration-response or dose response relationship Exposure conditions under which effects observed (i.e. amount deposited, dose, concentration, duration, pattern) Populations differentially affected (susceptible) Elements of ecosystem affected or more sensitive (e.g. regions, groups, populations, functions) Lag structure of PM associations morbidity and	Relatively few monitoring sites have appropriate colocation of monitors for computing $PM_{2.5-10}$. UFPs not measured as part of AQS or other routine regulatory network. While limited, available evidence indicates greater spatial variability in $PM_{2.5-10}$ than $PM_{2.5}$, resulting in increased exposure error for larger size fraction (p. 2.8). Background Considerable spatial and seasonal variation PM size, composition; source contribution.

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
			mortality	On average, $PM_{2.5}$ and PM_{10} correlated with each other more than gaseous co-pollutants. Exposure – source; topography; urban environment; loss processes (gravitational settling for $PM_{2.5-10}$ & coagulation for UFPs); activity (including transport & ventilation options); seasonality; temperature; humidity
The burden of disease and injury in Australia 2003 2007 (Begg et al., 2007)	Begg et al AIHW PHE 82			Over 3,000 deaths/year are attributable to air pollution; half associated with particulates. Urban air pollution responsible for 1% of the total burden of disease and injury, 62% due to CVD (ischaemic heart disease and stroke); 13% COPD and 21% lung cancer.
Factors influencing the spatial extent of mobile source air pollution impacts: a meta-analysis (Zhou & Levy, 2007)	(Zhou and Levy, 2007) BMC Public Health 2007 7:89	Examined literature on "hot spots" and spatial gradients in exposures to and health risks from traffic-related air pollutants	Conducted a quantitative literature review (1997-2005), looking at the spatial extent of mobile source air pollution and the factors that best explain variability	Spatial extent was indicated to be: • 100–400 m for elemental carbon, and for particulate matter (PM) mass concentration (which includes ultrafine [0.1µm] and fine [2.5µm] PM) • 200–500 m for nitrogen dioxide • 100–300 m for ultrafine particle counts ($PM_{0.1}$).
The effects of air pollution on hospitalisations for cardiovascular disease in elderly people in Australian and New Zealand cities (Barnett, Williams, Schwartz, Best, Neller, Petroeschevsky, & Simpson, 2006)	Barnett et al (2006) Environ Health Persp 2006; 114:1018-23	Estimate the associations between outdoor air pollution and elderly CV hospital admissions	Used case-cross over method for 7 cities; results were combined across cities using random effects meta-analysis and stratified for adults 15-64 and 65+. Considered NO, CO, PM and ozone.	*"The results suggest that air pollution arising from common emission sources for CO, NO_2, and PM (e.g., motor vehicle exhausts) has significant associations with adult cardiovascular hospital admissions, especially in the elderly, at air pollution concentrations below normal health guidelines."*
Health Effects of Fine Particulate Air Pollution: Lines that Connect (Pope & Dockery, 2006)	Pope & Dockery (2006) Journal of the Air and Waste Management Association 2006; 56(6): 709-742	Research approaches that have been pursued since the late 1990s to understand the effects of PM on human health	Describes characterisation of PM air pollutants and analyses six lines of research: Short term exposure and mortality (meta-analyses [systematic quantitative reviews]; single and inter-city studies) Longer term exposure and mortality (Harvard six Cities and ACS studies; reanalyses and extensions of Harvard work; other independent studies)	Consensus on evidence for impact on CVD morbidity and mortality. There is no evidence of a safe threshold concentration below which adverse health effects of PM are not observed Gaps in knowledge remain, including: • Understanding who's most at risk (most

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
			Time scale of exposure (intermediate time scales; daily time series) Analysis of the shape of the concentration (exposure)– response function (multicity daily time series; cross-sectional and prospective cohort studies) Impact of PM on cardiovascular disease (long and short term exposure and disease; physiologic measures of cardiac risk) Biological plausibility and pathophysiological or mechanistic pathways that link exposure with disease or death	susceptible), which is dependent on specific health end point being evaluated and the level and length of exposure. Known: cohort of those at risk of death or hospitalisation from acute increase in exposure is smaller than those susceptible to less serious effects from longer term exposure; and cumulative impacts more likely to be observed in latter in older age groups with longer exposures and higher baseline of mortality risks. Also known characteristics influencing susceptibility e.g. pre-existing CVD, diabetes, socioeconomic status, educational attainment etc. • Infant-birth outcomes. Impacts of PM on child health good evidence but effects on other birth outcomes "substantially less well established and understood" • Uncertainty on the effect of ambient PM on lung cancer- literature indicates combustion related ambient PM air pollution may result in small increases but gaps and difficulties associated with influence other factors e.g. smoking • Relative toxicity and role of sources and co-pollutants i.e. impact of single and combined sources combined with variation in PM characteristics • Other: methodological issues to be aware of Weak or uncertain associations combined with confounders of measuring error or model building Science in contested regulatory space
The short-term effects of air pollution on daily mortality in four Australian cities (Simpson et al., 2005)	Simpson et al (2005) Aust NZ J Public Health 2005; 29:205-12		Single city and pooled results using daily data for ambient particles (light scattering by nephelometry) and mortality from state Health Departments and the ABS for period 1996-99 in four cities (Brisbane, Melbourne, Perth and Sydney). Protocol similar to that used in European Air Pollution and Health: A European Approach 2 (APHEA2) studies	Air pollutants have significant effects on mortality- meta-analyses carried out for three cities resulted in estimated increase in the daily total number of deaths of 0.2% for a 10μ/m^3 increase in PM_{10} concentration (Brisbane, Sydney Melbourne) and 0.9% for a 10μ/m^3 increase in $PM_{2.5}$ (Sydney, Perth and Melbourne) Lacked common data set for PM_{10} and $PM_{2.5}$ and both data sets from Melbourne missing

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
				significant proportion of data (30%). Conclude should consider as indicative results, but consistent with other studies.
Health Impacts of Ultrafine Particles Desktop Literature Review and Analysis (Morawska & Moore, 2004)	Morawska et al (2004) Department of Environment and Heritage, Canberra, Australia	Desktop review and analysis of health impacts of ultrafine particles to establish state of knowledge and make recommendations for research priorities		Relatively small number of epidemiological studies, focus on acute health effects from short term exposure – need for further work including standardised measuring techniques, establishment of database and studies into concentrations, chemistry, source contribution etc. Overall- Both fine and ultrafine particles appear to affect health outcomes (mortality and respiratory and CV morbidity) and appear to do so independently of each other Findings from studies include: mortality data suggest UFP have more delayed effects; there is an indication that the acute effects of the number of UFP on respiratory health are stronger than fine
Health aspects of air pollution (WHO Working Group, 2004)	WHO Europe (2004) WHO Regional Office for Europe, Denmark			No evidence for threshold concentration below which adverse health effects of PM are not observed. Therefore, where PM exposures are low relative to air quality standards there is still health benefits to be gained by further PM reductions, especially in areas of high population density.
Cardiovascular mortality and long term exposure to particulate air pollution: epidemiological evidence of general pathophysiological pathways of disease (Pope et al., 2004)	Pope et al (2004) American Heart Association 2004; 109:71-77	Refine understanding of fine PM exposure and broad cause of death mortality to association with specific types of cardiopulmonary disease	American Cancer Society data (Cancer prevention II study) linked with air pollution data from US metropolitan areas; Cox Proportional Hazard regression models used to associate mortality to IHD, dysrhythmias, heart failure and cardiac arrest	While smoking is a much larger risk factor, fine PM air pollution is also a risk factor for cause-specific CVD mortality; mechanisms likely to include pulmonary and systemic inflammation, accelerated atherosclerosis and altered cardiac autonomic function. In terms of respiratory disease only pneumonia and influenza deaths in never smokers was associated with PM; otherwise air pollution primarily exacerbation of existing disease.

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
Lung Cancer, Cardiopulmonary Mortality, and Long Term Exposure to Fine Particulate Air Pollution (Pope et al., 2002)	Pope et al (2002) JAMA 2002; 287(9): 1132-1141	Associations but studies to date not yet conclusive re long term PM exposure and adverse health outcomes – focus on all cause, lung cancer and cardiopulmonary mortality	The study drew on vital status and cause of death data from the American Cancer Society ongoing prospective mortality Cancer prevention II study. (1.2million adults enrolled in 1982). Participants completed a survey of individual risk factors and demographic data. Risk factor data for 500,000 adults were linked with air pollution data for metropolitan areas throughout the USA and vital status and cause of death data to end 1998.	Long-term exposure to combustion-related fine particulate air pollution is an important environmental risk factor for cardiopulmonary and lung cancer mortality. Fine particulate and sulfur oxide–related pollution were associated with all-cause, lung cancer, and cardiopulmonary mortality. Each 10-µg/m^3 elevation in fine particulate air pollution was associated with approximately a 4% all cause, 6% cardiopulmonary and 8% lung cancer mortality. Measures of coarse particle fraction and total suspended particles were not consistently associated with mortality.
Confounding and effect modification in the short-term effects of ambient particles on total mortality: results from 29 European cities within the APHEA2 project (Katsouyanni et al., 2001)	Katsouyanni et al (2001) Epidemiology 2001 Sep;12(5): 521-31	Results of the Air Pollution and Health: A European Approach 2 (APHEA2) project of short term effects of ambient particles on mortality	Daily measurement of PM_{10} or less and/or black smoke in 29 European cities (43M people), over 5 years in 1990s, having regard to confounders Note: This paper has been cited in a range of subsequent studies	For every increase of 10µg/m^3 of daily PM10 There was an increase in deaths all causes of 0.6% and n the daily number of deaths for all ages for a increase in daily PM10 or black smoke concentrations was 0.6% (higher for the elderly) and a 0.7% increase in CVD deaths Of all pollutants, NO_2 concentration had the most important effect. Other factors e.g. health status of population, climatic conditions confirmed as having effect.
Associations between Mortality and Air Pollution in Central Europe (Peters et al., 2000)	Peters et al (2000) Environmental Health Perspectives 2000; 108(4): 283-287	Comparison of mortality and air pollution in highly polluted region of the Czech Republic and a rural setting in Germany	Mortality data linked with air pollution data from local stations (checked for plausibility and correlations). Poisson regression analyses conducted, with trend, season, meteorology, and influenza epidemic confounders considered	Increase in mortality associated with the concentration of PM in a highly polluted setting in Central Europe consistent with associations observed in other western European cities and US. In Czech Republic: 3.8% increase in mortality associated with 100 µg/m^3 TSP (lagged 2 days) i982-1994 In last 2 years of study, 68% of the TSP consisted of PM_{10}. An increase of 100µg/m^3 TSP (lagged 1 day) was associated with a 9.5% increase in mortality and 100µg/m^3 PM_{10} (lagged 1 day) a 9.8% increase in mortality.
A chronic Inhalation Toxicity Study of Diesel Emissions	Lewis et al (1989)	Evaluate potential health hazards of diesel engine	Inhalation studies on 3 animal species (mice, rats, monkeys) exposure up to 24 months filtered	Gross morphology and histopathology demonstrated that both diesel and coal dust

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
and Coal Dust, Alone and Combined (Lewis, Green, Moorman, Burg, & Lynch, 1989)	International Journal of Toxicology March/April 1989 8: 345-375	emissions in underground coal mines	ambient air, and diesel particulate and respirable coal dust at 1 and 2 mg/m^3 7h/day, 5d/week for up to 24 months	particles are deposited in the lungs and retained in alveolar tissue. Pulmonary function studies in monkeys showed mild obstructive airway disease in coal dust, diesel exhaust, and the combined exposed animals. This effect was most pronounced in monkeys exposed to diesel exhaust. Synergistic effects between diesel exhaust and coal dust were not demonstrated.
Cancer Mortality (1965-77) in Relation to Diesel Fume and Coal Exposure in a Cohort of Retired Railway Workers (Howe, Fraser, Lindsay, Presnal, & Yu, 1983)	Howe et al (1983) Journal of the National Cancer Institute 70(6): 1015-1019	Cancer mortality association with diesel fume and coal	A cohort study of 43,826 male pensioners of the Canadian National Railway Company, with cause of death of 17,838 pensioners who died between 1965-77 via linkage to the Canadian national mortality data base	Elevated risk of lung cancer for those employed in occupations involving exposure to diesel fumes and coal dust. The elevations are highly significant and show increasing risk with increasing level of exposure That the association may be due in part to smoking can't be excluded
Proximity to coal mines and coal generated power stations and health				
Investigating the health impacts of particulates associated with coal mining in the Hunter Valley (Dalton et al., 2014)	Dalton et al (2014) Air Quality and Climate Change Volume 48 No. 4. November 2014	Challenges of health studies in small populations like Hunter Valley; report on studies to date	Reviews methodological challenges of air quality-health studies; studies undertaken in the Hunter including NSW Health (2010); Merritt et al (2010) and other studies near open cut coal mines – noting limits and mixed outcomes of findings. Summarises publicly available air monitoring data for upper and lower Hunter valley towns relative to international findings. Comments on issues with placement and interpretation of monitoring data; and limits of using emission inventory data as a proxy for human exposure	• Need to integrate understanding of dose response relationships between particulate exposure and health outcomes from large population based studies • Comprehensive air monitoring program proposed to obtain good measures of variation in exposure • Relative to international standards air quality good although monitoring data shows annual average PM2.5 exceeded NEPM standard 8µg/m3 in Muswellbrook and Camberwell; absent of PM2.5 thresh-hold below which no one affected leads to conclusion important to safeguard against any deterioration in airshed. May be better to limit incremental increases in pollution rather than planning to allow levels to rise to a designated cumulative limit • Challenges of epidemiological studies on association between air pollution and health impacts: difference between lowest and highest levels of pollution is often less than

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
				three-fold and lack unexposed subjects. Need large scale for power; confounders (temperature, smoke, socioeconomic status); effect sizes small (smaller studies likely to miss small but important impacts). ● Challenges cross-sectional studies (current exposure and current health status) more feasible but difficult to interpret as past exposure more likely to be cause of current health status
The health of Hunter Valley communities in proximity to coal mining and power generation, general practice data 1998-2010 (Merritt et al., 2013)	Merritt TD et al (2013) NSW Public Health Bull. 2013 Nov; 24(2); 57-64	Population health in areas proximate to coal mining and power generation	Review of general practice data lodged through the Bettering the Evaluation and Care of Health (BEACH) program for rural communities in close proximity to coal mining and coal-fired power generation in the Hunter Valley was compared with data for all other rural NSW residents	No evidence of significantly elevated health issues for residents in the Hunter Valley. However, the rate for respiratory problems did not change significantly for the Hunter Valley group, but was significantly lower for the remainder of NSW, which is worthy of further inquiry
Respiratory and cardiovascular diseases and cancer among residents in the Hunter New England Area Health Service (NSW Health, 2010)	NSW Health (2010) Population Health Division, NSW Department of Health	Health and disease profile compared to wider state statistics	Draws on routinely collected health data (attendance at emergency departments [EDs], hospital separation [HS] and population health survey [PHS] for period 2007-09) for residents in HNE AHS [HNE] - in close proximity to coal mining and power generation (six fold increase open cut mining over last 3 decades and 4 of 6 coal fired stations in scope- Muswellbrook ('M') and Singleton ('S') LGAs. Limits: hospital data may represent use rather than morbidity; coding may be inconsistent; health service data does not directly compare exposed and unexposed communities; in 2009, pandemic (H1N1) influenza virus caused significant increases in ED presentations across NSW for all types of respiratory illness, and smaller increases for asthma presentations	Mixed picture ED: presentations for all respiratory illnesses in M and S higher than total for HNE & Sydney but below 3 other major LGAs in HNE (all ages); M has highest LGA asthma presentations ages 0-34 but 2-3 other LGAs higher in older age groups with S 3rd highest for those aged 35-64); M & S have highly ranked ED presentations for conditions unrelated to air pollution HS: M and S have higher HS rates CVD than all HNE or NSW but other HNE LGAs also do; M higher HS rate but S lower for all respiratory disease compared with NSW; mixed pattern for asthma also. PHS: no differences on key data self-reported health and differences in higher adult asthma outside areas with high exposure to coal mines or stations Report notes that "*There are no published Australian cohort studies on the association between particulate matter and long term deaths*." (p. 53).
Proximity to rail freight lines or yards and health				
Respiratory Health Risks for Children Living Near a Major	Spencer-Hwang et al	Assess proximity to rail yard and respiratory health	Health impacts on elementary school children located approx. 800metres from the San	Children attending school near the railyard were significantly more likely to display respiratory

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
Railyard (Spencer-Hwang, Soret, Knutsen, Shavlik, Ghamsary, Beeson, Kim, & Montgomery, 2015)	J Community Health (2015) 40:1015–1023 Ca, USA	in school children	Bernardino Railyard (intermodal facility), one of the busiest goods movement facilities in Ca, matched with children at school 7 miles (11km) away. Respiratory screening undertaken at the two schools and parental logs and surveys	health challenges, including airway obstruction with higher prevalence of abnormal peak expiratory flow. However, the association with inflammation was less clear. 2014 qualitative study by same group Experience of a Rail Yard Community: Life is Hard –notes socio-economic disadvantage of community and multiple challenges; air quality specific: point source monitoring, clean engines, vegetation border & other strategies recommended
Global trade, local impacts: lessons from California on health impacts and environmental justice concerns for residents living near freight rail yards (Hricko, Rowland, Eckel, Logan, Taher, & Wilson, 2014)	Hricko et al (2014) Int J Environ Res Public Health 2014; 11(2):1914-41	Profile of populations living in the highest estimated cancer risk zones near 18 major rail yards in Ca	Describes cancer risks for residents in Ca USA living in close proximity to rail yards with emissions of diesel particulate matter pollution from locomotives, trucks and yard equipment; and the demographics (income, race/ethnicity) of residents	The majority are over-represented by either lower-income or minority residents (or both).
Corridor-Level Air Quality Analysis of Freight Movement - North American Case Study (Farzaneh, Lee, Villa, & Zietsman, 2011)	Farzaneh et al (2011) Journal of the Transportation Research Board	Methodology to assess impact of truck and rail freight on air quality along rail corridors, using Mexico City to Montreal Canada route	Network and freight activity data established for base (2010) and future (2035) case linked to emission rates from US EPA emission model (MOBILE6.2). Rail emission calculations based on average emission and fuel consumption, revised to reflect ongoing improvements in locomotive engine standards	Current levels of emissions not significant compared with trucks, however, share of rail for some pollutants (PM and NOx) emissions will continue to increase over time and will be significant Need for improved analytical tools and estimation methods for rail fuel consumption and emissions. Limits: high level of uncertainty in rail freight movement data and emission estimate methods aggregate- therefore large uncertainty for estimating rail emissions
An analysis of the health impacts from PM and NO_X emissions resulting from train operations in the Alameda Corridor, CA USA (Sangkapichai et al., 2010)	Sangkapichai et al (2010) University of California Transportation Center, UCTC Research Paper No. UCTC-FR-2010-10	Estimate the health impacts of exposure to PM and NO_x emitted by train operators in the Alameda Corridor	Linked a pollutant dispersion model (CalPUFF) to a benefits assessment model (BenMAP) to identify population impacts of PM and NO_X emissions from switching and line haul train operations; followed by 2 scenarios to assess benefits of changing to USA Tier 2 to Tier 3 locomotives	Mortality from PM accounts for largest health impacts, with health costs of $40M annually Switch to Tier 2 locomotive would save half of the annual health costs but switch from Tier 2 to Tier 3 benefits much smaller Limits: gaps in available health data
Development of an Exposure	Rahai (2008)	Develop model to assess	Approximate $PM_{2.5}$ concentration for diesel	Results indicate between10-15% increase in PM

Title Date/ Stage / Jurisdiction	Author	Focus/ Questions addressing	Methods	Results/ Conclusions
Model for Diesel Locomotive Emissions near the Alameda Corridor USA (Rahai, 2008)	Center for Energy and Environmental Research and Services, California State University	exposure risks of PM concentration	locomotive emissions was obtained using a TSI DustTrak aerosol monitor; and wind speed and direction using a Young model 85000 2-axis anemometer. Measurements were carried out at different distances from the railroad from -4.6M (other side of railway) to 90M, with readings taken on different days.	concentration from the passage of the diesel locomotives. Instrumentation used meant not able to distinguish small particles and fractions.
Roseville Rail Yard Study USA (Hand, D, Servin, Hunsaker, & Suer, 2004)	California EPA Air Resources Board	Conducted a health risk assessment of airborne PM emissions from diesel locomotives at the yard located in Roseville, CA	Developed inventory of diesel PM emissions from the yard; conducted computer modelling to predict increases to ambient levels in the local area; assessed potential cancer risk from exposure to diesel PM	• The assessment showed elevated concentrations of diesel PM and associated cancer risk impacting a large area. • *Potential cancer risk and the number of acres impacted for several risk ranges are as follows:* o *Risk levels between 100 and 500 in a million occur over about 700 to 1,600 acres in which about 14,000 to 26,000 people live.* o *Risk levels between 10 and 100 in a million occur over a 46,000 to 56,000 acre area in which about 140,000 to 155,000 people live.* • The magnitude and general location of the risk and the size of the area impacted varies depending on the meteorological data, the dispersion characteristics, and the assumed exposure duration and breathing rate for the proposed population, but were suggestive of needing short and long term mitigation measures.

APPENDIX 4. POSSIBLE MITIGATION STRATEGIES IN THE COAL SUPPLY CHAIN

Transport assets, operation & management[1]	Pre-loading & loading	In transit	Unloading	Transfer
Design, upgrade and optimally maintain assets to minimise emissions Required EPL Maintenance[2]	**Optimise loading practises to assure appropriate loads and profile and reduce spillage** Applied EPL Operating; Relates to Required EPL Wagon Monitoring and Reporting EIP	**Minimise emissions and spillage in corridor and dispersion beyond corridor** Required EPL Dust	**Reduce coal 'plough', spillage, dust generation and circulation pathways, carry out** Required EPL Dust	**Reduce wind exposure, dust generation, lift off and circulation pathways** Required EPL Dust
Wagon design e.g. spoilers/ deflectors at front to prevent parasitic coal; container/ hungry boards to prevent spillage over side Applied EPL Operating	**Type of coals accepted into supply chain** Industry choice	**Limit capacity of the corridor (e.g. reduce speed, number of train movements)** Not required (except some mine extension consent conditions)	**Unload within building or shed** Applied EPL, Dust	**Use of conveyor containment chutes and wind** shields e.g. hungry boards; roofs to transport to/ from stockpile Applied EPL Operating
Wagon door design or adjustment to reduce leakage; seal gap; install rubber seals; optimise release and clearance rate Applied EPL Operating & Maintenance	**Ensuring coal is at the correct DEM level to produce minimal dust (if needed, washing coal at mine; reapply in transit)** Industry choice	**Cleaning of the corridor to minimise re-entrainment including key juncture points** Required EPL PRP 5	**Install dust collection system e.g. fabric filter** Not required	**Placement & type of equipment to minimise disturbance** e.g. bucket wheel reclaimer Applied EPL Operating; Dust
Optimal wagon and locomotive fleet maintenance Required: EPL Maintenance	**Apply water or chemical suppressant at mine site (either on surface or stockpile)** Industry choice as relevant	**Veneering of the corridor** Not required	**Automatic unloading system e.g. door triggers to unload; directly into hopper** Applied EPL Operating	**Variable height of stackers/shiploaders to minimise distance of drop** Applied EPL Operating; Dust
Retrofit emission kits to existing fleet locomotives Pilot EPA with industry	**Load coal within building or shed or use of fully integrated system** Industry choice	**Barriers in rail corridor (e.g. walls, trees, etc.) to minimise emissions out of corridor** Not required	**Manage process** e.g. minimise distance of drop; rapid clearing; minimal opening; managed flows; match train speed to unloading rate Applied EPL Operating	**Configuration of stockpile** e.g. location relative to other activities/ residential areas; orient relative to wind direction Applied EPL Operating; Dust

Transport assets, operation & management[1]	Pre-loading & loading	In transit	Unloading	Transfer
Upgrade locomotives Not required	**Install dust collection system e.g. fabric filter** Not required	**Apply/ reapply water/ chemical suppressant to wagons at head of corridor/ entry to major population centres/ trips > 2hours** Not required	**Monitor to assure receivers aren't overfilled** e.g. CCTV, direct observation Required EPL Wagon Monitoring and Reporting EIP	**Pivot stacker to avoid need to use bulldozer or similar to reconfigure stockpile** Applied EPL Operating; Dust
Use high quality fuel Industry choice	**Use automated systems to load correct amount in optimal configuration and minimise spillage** e.g. identify wagon type and tare; batch weighing systems to load; telescopic chutes to profile load Applied: EPL Operating; Dust	**Standardise driver practices (acceleration/deceleration etc.)** Industry choice	**Water suppressant during unloading** Applied EPL Operating	**Cover stockpile or shield stockpile e.g. walls, wind breaks** Applied EPL Operating; Dust
Maintain track integrity (vibrations) Required EPL Maintenance	**Use of standardised loading/profiling requirements (adjusted for wagon type, load) for regular (garden bed) surface to minimise expected lift off** Applied EPL Operating; Dust	**Monitoring emissions in corridor** Required EPL PRP 4.1 and 4.2	**Ensure bottom doors are properly closed after unloading** Required EPL Wagon Monitoring and Reporting Environmental Improvement Program	**Water spray stacker boom tip when unloading and conveyors especially at transfer points** Applied EPL Operating; Dust
	Scanners/ profilers to identify and manage excess load height Relates to Required EPL Wagon Monitoring and Reporting EIP		**Monitor unloaded wagons to check for residual coal** Required EPL Wagon Monitoring and Reporting Environmental Improvement Program	**Surface treat stockpile** e.g. water spray/ chemical(s) for specific coal types/ periods Applied EPL Operating; Dust
	Maintain freeboard (container/ hungry boards) around edge of wagon Not required		**Wagon vibrators to clear residual coal** Not required	**Maximise direct loading; minimise time on stockpile** Applied EPL Operating; Dust
	Full or partial covers on wagons or installation to some wagons		**Clean wagons/ wheels on exit e.g. spray, wash, brush, pressurised air out-/in-side of wagon; clean**	**Equipment maintenance and cleaning** e.g. conveyor belt

Transport assets, operation & management[1]	Pre-loading & loading	In transit	Unloading	Transfer
	(train configuration dependant) Not required		**exit tracks** Applied: EPL Operating; Dust	scrapers and cleaners/ washing Required EPL Maintenance
	Monitoring or limiting loading practices Applied EPL Operating and Dust		**Rail loop design (will influence efficiency of process; minimisation of spillage; proximity to community etc.) and control system** May be considered as part of Planning assessment process	**Spillage minimisation** e.g. conveyor chute skirts; management systems (conveyor gallery design for rapid floor and surface entrapment and cleaning) Spillage minimisation required EPL; Dust
				Meteorological and/or dust monitoring and sampling-continuous; real time Required EPL Monitoring

1. Assumes operator education for all strategies; excludes regulatory actions e.g. establish standards; encourage/ enforce compliance with selected strategies
2. Required Operating: Required under EPL "Activities must be carried out in a competent manner"; Required Maintenance: Required under EPL: "All plant and equipment…must be maintained… must be operated in a proper and efficient manner; Required Monitoring: Required under EPL: Requirements for monitoring points and type; concentration of pollutants discharged; maintain records and report; Required PRP: Required under EPL Pollution Studies and Reduction Programs; Applied: regarded as industry good practice and observed to be considered in audits and compliance assessment; Industry Choice: no requirement; variable industry application; Not required: not required and not known to be applied in NSW

APPENDIX 5. PARTICULATE AIR EMISSIONS MONITORING TECHNOLOGIES

#	Technology	Property measured	Description	Advantages	Disadvantages
1. Technologies to measure airborne particle mass concentration					
1.1 Direct reading (gravimetric)					
a)	Dust deposition gauge	Particle mass (Dust fall or nuisance dust)	• Simple piece of monitoring equipment with a glass funnel supported in the neck of a large glass bottle. • For monitoring in accordance with Australian Standard 3580.10.1:2003.	• Ideal for long term, low cost monitoring. • Absolute calibration. • Collected samples may also be used for chemical composition and thus source identification.	• This technique would be unsuited to measuring air emissions in the rail corridor without augmentation with another method due to coarse temporal resolution (1 month sampling). • Inaccurate for particles < 5 µm and rare for these traps to collect particles > than 200µm.
b)	High and low volume air sampling onto filters	Particle mass concentration; selective sizes	• Both high (e.g.: HiVol) and low volume (e.g. Partisol) samplers collect air samples on a filter which is weighed before and after collection. • The upper size limit is determined by a size selective inlet located upstream of the filter, usually sized for TSP, PM_{10}, $PM_{2.5}$ or $PM_{1.0}$. • The difference between high and low volume air samplers is the amount of air sampled (1000L/min for high volume and 3 to 17L/min for low volume). • Measurement particle size range is constrained by the size selective inlet, where used, and the capture size of the particle filter. Absolute filters are normally used. Upper size range of about 50µm (high volume). • Lower detectable Limit (mass): dependent upon sampling time and weighing technique.	• Meets NEPM reporting requirements. • Australian standard exists. • Collected samples can also be used for chemical composition and thus source identification. (Depending upon the filter media used). • Sampling equipment moderately priced. • Low volume samplers can be battery operated and portable.	• Off-line gravimetric mass measurement requires infrastructure and equipment. • Relatively time intensive. • Sample collected over a period of time (usually 24 hours) so that time resolution is poor. • Generally both high and low volume samplers take a 24 hour sample at 6-day intervals. • High volume samplers need 240V.
c)	Tapered element oscillating microbalance (TEOM)	Particle mass concentration; size distribution based on mass due to dichotomous particle	• Low volume air sampler that continuously weighs particles deposited onto a unique filter system. • The upper size limit is determined by a size selective inlet positioned upstream of the	• Meets NEPM reporting requirements • Australian standard exists • Sampling equipment	• Sample is generally heated to 50°C so volatile mass lost; this can be mitigated by use of FDMS which increases price

#	Technology	Property measured	Description	Advantages	Disadvantages
		sizer	filter allowing measurement of TSP, PM_{10}, $PM_{2.5}$, $PM_{1.0}$. • A Filter Dynamics Measurement System (FDMS) can be added to the TEOM that measures the aerosol mass lost due to volatilisation (the standard TEOM is usually operated at 50°C). • The FDMS allows concurrent measurements of PM_{10} and $PM_{2.5}$ using a dichotomous particle sizer in addition to dual TEOM elements. • Measurement range (mass): 0 – 0.5µg/m^3 (24hr average)	moderately priced to highly priced • High time resolution • Provides calibrated mass measurements. • Operate continuously and generally do not need filter changes as frequently as high-volume air samplers do. • Analysers can provide additional information, such as the time of day that peak particle concentrations occur. • Used in conjunction with meteorological and chemical analyses data, TEOMs can help identify sources of particle emissions.	• Needs 240V, a special air conditioned cabinet and is not portable. • Calibration, temperature and humidity issues have to be taken into account.
d)	Cascade impactor	Mass size distribution, can give size selectivity (w/ LEPI) with chemical analysis (offline) – versatile instrument	• Cascade impactors are multi-stage aerosol samplers used to collect size-fractionated particle samples for chemical and gravimetric analysis. The addition of particle charging and electrometer systems can allow for real time monitoring of particle concentrations, Electrical Low Pressure Impactor (ELPI).	• Collected samples can also be used for chemical composition and thus source identification. • ELPI has high time resolution (1Hz) • Sampling equipment moderately priced.	• The cascade impactor would be unsuited to measuring air emissions in the rail corridor without the augmentation of the ELPI as samples are collected over a period of time (usually 24 hours) so that time resolution is poor.
1.2 Indirect reading (sampling and analysis)					
e)	Beta attenuation monitor (BAM), optical mass	Particle mass concentration, scattering coefficient; selective sizes	• Particles are deposited on a filter tape after size filtering. A Carbon-14 source produces beta particles whose absorption in the tape (after calibration) is proportional to the mass of particles on the tape. • Measurement range: The upper size limit is determined according to the size selective inlet located upstream of the filter tape, and is usually TSP, PM_{10}, $PM_{2.5}$ or $PM_{1.0}$. • Lower detectable Limit (mass):~0.5µg/m^3	• Meets NEPM reporting requirements • Australian standard exists • Sampling equipment moderately priced • Time resolution can be increased by inclusion of light scattering devices in	• Sampling time depends on deposition rate of particles but is typically hours. • Calibration, temperature and humidity issues have to be taken into account. • Needs 240V, a special air conditioned cabinet and is not portable.

#	Technology	Property measured	Description	Advantages	Disadvantages
			(24hr average)	some models. • Relatively small, lightweight.	
f)	Light-scattering optical particle counter (OPC), also referred to as nephelometer or aerosol photometers	Particle mass concentration, scattering coefficient; particle size distribution **Note:** includes low angle forward scattering (e.g. OSIRIS) and 90° side scattering (e.g. DustTrak and GRIMM) – all infer mass through algorithms from optical properties	• Pump draws air through a proprietary nephelometer (a device to measure light scattering in turbid media) to simultaneously infer mass (and number) concentrations for selected particle sizes from scattered light. Particles can be collected on a reference filter to provide mass calibration. • E.g.: Optical Scattering Instantaneous Respirable Dust Indication System (OSIRIS), DustTrak, Esampler, Fine Dust Analysis Systems (FIDAS) • Forward light-scattering measurement range (particle size): 0.3 – 20µm (GRIMM) • Backward light-scattering measurement range (particle size): 0.1 – 10µm; side-scattering measurement range (particle size): 0.1 – 50µm (RAND Corporation, 1998) • Measurement range (mass): 0.1µg/m^3 (OSIRIS), 1mg – 150mg/m^3 (DustTrak), 0.01g/m^3 to 6mg/m^3, (GRIMM)	• Australian standard exists (for nephelometer although not for mass calculation). • Sampling equipment low to moderately priced (DustTrak cost is $5-10k depending on options). • High time resolution (between 1-s and 5-min for GRIMM). • Battery operated, handheld, can be calibrated. • Some instruments have the ability to measure TSP, PM_{10} & $PM_{2.5}$ simultaneously (Institute of Air Quality Management, 2012).	• Nephelometers are calibrated to a known particulate, and then use environmental factors (k-factors) to compensate for lighter or darker coloured dusts, different particle density and shape depending upon the scattering technique used by the particular monitor. (see footnote 1) • Mass scattering coefficient needs to be determined to calculate mass from scattering coefficient. • Australian Standards do not exist for the determination of mass concentration from nephelometers
2. Particle number counters					
–	OPC	As per f) and particle count; size distribution according to particle number	• Discussed at f) • Measurement range (number): 1 – 20,000 particle/cm^3 (FIDAS), 1 – 70 particle/cm^3 (GRIMM)	• Discussed at f)	• Discussed at f)
g)	Scanning Mobility Particle Sizer SMPS™ spectrometer	Particle count; size distribution according to particle number (can do indirect calculation of mass based on multiple assumptions with high uncertainties)	• SMPS measures the concentration of particles as a function of particle diameter using the property of particle electrical mobility. • SMPS measures the number size distribution of particles between ~5nm and 700nm at usually 5 minute intervals. • Measurement range (particle size): 1nm – 1000nm (TSI Inc. Model 3938) • Concentration range: 20 – 107 particles/cm^3	• SMPS provides high quality data on particle number and mass size distribution that can be used to infer information on formation process and sources. • SMPS has time resolution (around 5 minute intervals)	This instrument would be unsuited to measuring air emissions in the rail corridor without augmentation with another method as SMPS can only measure particle sizes up to ~800nm (0.8µm, $PM_{0.8}$) low uncertainties.
h)	Aerosol Particle	Particle count; size	• The APS measures the concentration of	• Provides high quality	This instrument would be unsuited

#	Technology	Property measured	Description	Advantages	Disadvantages
	Sizer (APS) spectrometer	distribution according to particle number, light-scattering intensity (can do indirect calculation of mass based on multiple assumptions with high uncertainties)	particles as a function of particle diameter by measuring the velocity of particles in an accelerating air flow through a nozzle using a time of flight (ToF) spectrometer. • Measurement range (particle size): 0.5µm – 20µm (APS model (3321) by TSI)	data on particle number and mass size distribution • High time resolution up to 1Hz	to measuring air emissions in the rail corridor without augmentation with another method as counting statistics for particles greater than 5µm are poor.
i)	Fast response particle spectrometer	Particle count; size distribution according to particle number	Fast response particle spectrometers number size distribution of particles between ~5nm and ~500nm at up to 10Hz.	• 10Hz for fast response particle spectrometer	
j)	Laser particle counters, includes Condensation Particle Counters (CPCs)	Particle count; particle number distribution **Note:** these generally only give particle number distribution unless they also measure light scattering, then they can measure as per f)	• Air is drawn through an analysis chamber past a tightly focused laser beam. • Particles are counted each time the laser beam is obscured. • Determine air quality by counting and sizing the number of particles in the air. • E.g.: Lighthouse Worldwide Solutions Handheld 2016. • Measurement range (particle size): >0.3µm for laser particle counter and 2.5nm – >3000nm for CPC (depending on specific model).	• Can be as simple as a handheld air monitoring instrument. • Depending on the model type, particle counters can detect PM as small as 0.1µm • Nano particle counters are being developed to count even smaller particles. • Portable particle counters offer features not found in handheld particle counters. Some of these features include thermal printing, filter scanning, air velocity, differential pressure, temperature and isokinetic sampling of ambient air.	• Used in clean rooms; can saturate (particle co-incidence) at high pollution levels. • Generally requires some pre-conditioning of the inlet gas stream for ambient environmental measurements.
k)	Open path optical scattering or diffraction	Particle size: (emerging technique)	• Uses laser diffraction to assess the size of particles by measuring the intensity of light scattered as a laser beam passes through a dispersed particulate sample. E.g.: Malvern Mastersizer • Measurement range (particle size): 0.01 – 3500µm with accuracy better than 1%.	• Has a substantial track record of deployment for environmental monitoring of dust and aerosols.	• The Malvern Mastersizer provides a proof of principle for this technique only.

#	Technology	Property measured	Description	Advantages	Disadvantages
3. Technologies to measure black carbon/ soot concentration					
l)	The particle soot absorption photometer (PSAP) is a widely used filter based instrument	Black carbon mass loadings based on optical absorption; selective sizes	• Filter-based techniques concentrate the deposited aerosols on filters. • In situ measurements of aerosol light absorption are based on the temperature increase of particles upon exposure to light. • Strongly absorbing particles may be from black carbon (coal dust or diesel emissions), moderately absorbing may be from soil/resuspended rail dust. • The upper size limit can be limited by the inclusion of a size selective inlet upstream of the filter allowing measurement of TSP, PM_{10}, $PM_{2.5}$ or $PM_{1.0}$. • 10s time resolution	• Provides real time measurements.	• A significant uncertainty associated with filter based techniques is that the filter substrates cause multiple scattering which complicates instrument calibration and interpretation of data.
m)	The Aethalometer® is also a widely used filter based opacity monitoring instrument	Optical absorption; selective sizes	• The Aethalometer® is an instrument that uses light analysis to determine the concentration of Black Carbon particles collected from an air stream passing through a filter in real time. • This instrument may measure absorption at up to 7 wavelengths. • The upper size limit can be limited by the inclusion of a size selective inlet upstream of the filter allowing measurement of TSP, PM_{10}, $PM_{2.5}$ or $PM_{1.0}$. • Measurement range (mass):<0.01 to >100µg/m^3 black carbon	One of the most-widely-used instruments for the real-time measurement of black carbon aerosol particles in the atmosphere.	• See common disadvantage of filter based measurement above. • The accuracy, and even the ability, of the Aethalometer to differentiate smoke sources are disputed (Harrison, Beddows, Jones, Calvo, Alves, & Pio, 2013)
n)	Multi-Angle Absorption Photometer (MAAP)	Black carbon mass loadings based on optical absorption; selective sizes	• Another filter based instrument, the MAAP measures loading of black carbon in the atmosphere using a radiative transfer scheme to particle loaded glass fibre filters. • This instrument only operates at a single wavelength (notionally 670nm). • The upper size limit can be limited by the inclusion of a size selective inlet upstream of the filter allowing measurement of TSP, PM_{10}, $PM_{2.5}$ or $PM_{1.0}$. • Measurement range (mass): 50ng/m^3 black carbon (30 minute average)	• The MAAP uses a correction method for multiple scattering by including the measurement of reflectivity of the filter at two angles and minimizing the cross sensitivity to particle scattering. • The MAAP includes a filter tape drive mechanism that allows	• A measurement artefact has been observed in the MAAP at high BC concentrations (Hyvarinen et al., 2013).

#	Technology	Property measured	Description	Advantages	Disadvantages
			• 10s time response	for automatic advance of the filter tape. • The combination of these two techniques means that the MAAP provides a highly accurate measurement of black carbon content.	
o)	Photo-Acoustic Soot Spectrometer (PASS)	Photo acoustic absorption and scattering; selective sizes	• The PASS is a photoacoustic instrument that measures the temperature increase of particles upon exposure to light • This results in the generation of a sound wave that is detected by a microphone. • The upper size limit can be limited by the inclusion of a size selective inlet upstream of the filter allowing measurement of TSP, PM_{10}, $PM_{2.5}$ or $PM_{1.0}$. • Measurement range (mass): 40ng/m^3 black carbon (30 minute average)	• The PASS measures absorption at single or multiple wavelengths. • The PASS can also measure particulate light scattering, which neither the Aethalometer nor the PSAP does. • PASS a significant advantage as that the measurement is made on aerosol in suspension rather than collected on a filter, so no corrections for filter effects are needed	• Both the photoacoustic and refractive index based measurements methods may suffer from some interference due to light induced particle evaporation. • Requires specialised skills to operate and analyse data.
p)	Single Particle Soot Photometer (SP2)	Absorption; selective sizes	• The SP2 is a commercially available incandescence-based instrument that uses a high-intensity laser to heat particles to very high temperatures and quantify this temperature change through measurement of their thermal emission spectrum. • Measurement ranges sourced from Droplet Measurement Technologies (DMT): o Measurement range (particle size):0.2µm – 0.5µm (typical) o Measurement range (mass): ~1fg/particle black carbon o Measurement range (number): 25,000 particles/second, 0-12,500 particles/cm^3 o Sensitive to soot mass in the range of 1–300 femtograms ($1x10^{-15}$g) per particle	• The SP2 while being high cost is the only instrument available that specifically identifies and quantifies black carbon without interference from other absorbing particles.	• High cost. • Requires specialised skills to operate and analyse data. • There is some evidence that the SP2 may not reliably detect soot nanoparticles (Gysel, Mensah, Corbin, Keller, Kim, Petzold, & Sierau, 2012)

#	Technology	Property measured	Description	Advantages	Disadvantages
q)	Tricolour Absorption Photometer (TAP)	Absorption; selective sizes	• The Tricolour Absorption Photometer is a low cost version of the filter based absorption instrument and is the commercialised version of the instrument used in the US government's National Oceanic and Atmospheric Administration (NOAA) aerosol network. • This instrument measures absorption at three wavelengths using LEDs as the light sources. • The instrument error is +/- $0.2 mm^{-1}$	• The TAP is simple to install, operate, and calibrate (RAND Corporation, 1998).	• See common disadvantages of filter based measurement above. • TAP requires specialised skills to operate and analyse data.
4. Technologies to measure chemical composition					
r)	**Offline chemical analyses:** Offline analyses are characterised by manual sampling followed by discontinuous sample preparation, measurement and evaluation.	Chemical composition	• Samples collected with aerosol samplers with size selective inlets (PM_{10}, $PM_{2.5}$ and PM_1) and analysed offline for chemical composition by specialised analytical methods. • Soluble ions which can be used to identify primary sources such as sea salt particles and secondary sources such as ammonium sulphate from coal fired power stations can be analysed by ion chromatography on Teflon, polycarbonate and quartz filters. • Elements that can be used to identify primary sources such as soil particles can be analysed by ion beam analysis on stretched Teflon and polycarbonate filters. • Black carbon which can help identify combustion sources by light absorption methods can be measured on Teflon or polycarbonate filters. • A coal grain analytical method using an optical reflected light imaging and analysis system has recently been developed for aerosol samples.	• The advantage of offline chemical analyses is the ability to identify sources of aerosols (in some cases with unique identifiers).	• Offline chemical analyses appear to be not useful for coal dust as it requires large sample volumes resulting in poor time resolution (typically 24 hours) and the artefacts that occur during and after sampling, particularly concerning volatile and semi-volatile compounds. • Source apportionment studies using positive matrix factorisation cannot distinguish between crustal matter containing resuspended black carbon from combustion sources or from coal sources.
s)	**Online chemical analyses:** Analyses which are connected to a process, and conduct	Chemical composition	• Online chemical analyses can be carried out using aerosol mass spectrometer (AMS) and the aerosol chemical speciation monitor (Q-ACSM). • These have been used routinely in Europe and North America, but currently are only	• Online analyses differ essentially from offline methods in that the time in which information about process or material properties is obtained is	• Both AMS and Q-ACSM instruments are of high cost and are not able to measure the chemical composition of coal since coal particles are refractory

#	Technology	Property measured	Description	Advantages	Disadvantages
	automatic sampling, are called online.		used for research purposes in Australia. • These instruments measure in real time the chemical composition and mass of non-refractory sub-micron particles. • Measurement range (particle size):0.04µm – 1µm (typical) • Detection limits depend upon the chemical species	shorter than the time in which these properties change.	(i.e. resistant to the vaporising temperature of 600°C used in the instruments).
t)	QEMSCAN®	Chemical composition	• Quantitative Evaluation of Minerals by SCANning electron microscopy (QEMSCAN®) is a technology developed by the CSIRO. It employs a scanning electron microscope, four X-ray detectors and a software package that enables a fully automated, non-destructive, micro-analysis system that provides rapid, statistically reliable and repeatable, mineralogical, petrographic and metallurgical data, from virtually any inorganic, and some organic, materials.	• CSIRO developed QEM*SEM™ – the technology that underpins QEMSCAN® – to automatically and rapidly analyse the mineralogy of metallurgical products, size-by-size; particle-by-particle. • A variety of quantitative information can be obtained including distribution, composition, and angularity of minerals, and the fabric, distribution, texture and porosity of materials (Ayling, Rose, Petty, Zemach, & Drakos, 2012) • Can analyse a wide range of particle size from small to large. • Fast	• Expensive
u)	Soot particle aerosol mass spectrometer (SP-AMS)	Measures black carbon mass, mass and chemical composition of any coating material (e.g. organics, etc.), and particle size and morphology	• SP-AMS makes real time measurements of size, mass, and chemical composition of sub-micron black carbon containing particles. • Uses laser-induced incandescence of absorbing soot particles to vaporise both the coatings and elemental carbon cores within the ionization region of the AMS.	• Provides a unique and selective method for measuring the mass of the refractory carbon cores (i.e., black carbon mass), the mass and chemical composition of any coating material	• Only measures sub-micron particles. • Very expensive. • Requires skilled operators.

#	Technology	Property measured	Description	Advantages	Disadvantages
		(emerging technique)	• Measurement range (particle size): ≤1µm (typical) • Sensitivity: SP-AMS (V-mode) > 140 carbon ions/pictogram. • Detection Limit on refractory black carbon: SP-AMS (V-mode): 30ng/m^3 • Detection limits on chemical species: organic DL is ~60ng/m^3 , sulphate DL is ~2ng/m^3	(e.g., organics, sulphates, nitrates, etc.), and particle size and morphology. • Time resolution and sensitivity is high; it specifically identifies and quantifies black carbon and other chemical components that can be used in source apportionment	
v)	Time of flight aerosol chemical speciation monitor (ToF-ACSM)	Measures quantitative particle mass loading and chemical composition in real-time for non-refractory sub-micron aerosol particles (emerging technique)	• The time of flight aerosol speciation monitor (ToF-ACSM) made by Aerodyne is similar to the Q-ACSM except it has a time of flight mass spectrometer (the Q-ACSM has a quadrupole mass spectrometer). • Measurement range (particle size): 40nm to 1 µm (vacuum aerodynamic diameter). • Measurement range (mass): 0.002µg/m^3 – 0.05µg/m^3 (dependant on model)	• Order of magnitude lower detection limits than Q-ACSM. • Ability to perform high resolution peak fitting to the spectra, which can help with source identification. • Suitable for long term sampling campaigns.	• Currently the aerodynamic sampling lens is for PM_1 with a $PM_{2.5}$ lens still in development. • Expensive • Requires skilled operators to operate and interpret data.
w)	Coal Grain Analysis (CGA)	Method of discriminating between microscopic coal particles and other particulates (emerging technique)	• Coal Grain Analysis (CGA) is a technique used by the CSIRO for the last 6 years and uses optical imaging techniques and analysis systems which provides a unique method of assessing parent and daughter particles to determine if liberation has occurred. • Estimates of size, compositional and density information on individual grains of fine coal can be obtained. • The method utilises a high-resolution optical system that can be 'trained' to discriminate between microscopic coal particles and other particulates like mineral dust, rubber, and soot from car exhaust or even plant fragments. • In the case of coal dust, the coal grain analysis methods commonly applied to coal dust have recently been adapted to airborne	• Measurement range (particle size) >PM_1.	

#	Technology	Property measured	Description	Advantages	Disadvantages
			particles collected on filters (Keywood & Selleck, 2016).		

1. Optical particle monitors, or light scattering based instruments, do not directly measure particle mass. Instrument manufacturers may also use different light scattering techniques, in addition to different algorithms, to calculate particle mass from measured optical data sets. Different optical techniques may incorporate varying mass biases according to the sensitivity of the technique to changes in particle optical properties such as reflectivity, and shape as well as particle density as well as the calibration methodology. Differences between light scattering techniques can influence both the accuracy and inter-instrument comparability of reported data sets and such biases and uncertainties need to be carefully evaluated.

Notes

- The information in this table is compiled from the information papers commissioned for the Review (Eggleton, 2016; Keywood & Selleck, 2016), other sources as referenced and manufacturer's websites. It is suggested that the reader consult the original source for more information and not rely solely on the information presented in the table.
- Coincident measurement of gas molecules (e.g.: VOCs, NOx, CO_2, PAHs etc.) may be undertaken to signal the presence of diesel emissions.

APPENDIX 6. SITE VISITS, STAKEHOLDER MEETINGS, TELECONFERENCES, AND SUBMISSIONS

Table 3: Site visits

Date	Location	Present
08/10/15	Various sites across the city of Newcastle and Sandgate	Environment Protection Authority representative
16/11/15	Kooragang Island, Aurizon Hexham Train Support Facility	Port Waratah Coal Services (PWCS) representatives, Aurizon representatives
12/1/16	Various sites across the city of Newcastle	Community members from Correct Planning and Consultation for Mayfield group (CPCFM)
12/1/16	Mt Owen train load-out facility, Liddell Unit Train Loading (UTL) facility,	Glencore, NSW Minerals Council

Table 4: Stakeholder meetings and teleconferences

Date	Type	Stakeholder Group/s
18/09/15	Meeting	Environment Protection Authority (members from Reform and Policy, Air Policy, Compliance and Assurance, Infrastructure and the Hunter Region.)
02/10/15	Teleconference	Environment Protection Authority (members from Hunter Region)
08/10/15	Meeting	Correct Planning and Consultation for Mayfield group (CPCFM)
13/10/15	Teleconference	Environmental Justice Australia
03/11/15	Meeting	NSW Minerals Council, Glencore Coal Assets, Centennial Coal, Aurizon, Pacific National, Australian Rail Track Corporation (ARTC), Port Waratah Coal Services (PWCS)
03/11/15	Meeting	Professor Louise Ryan, University of Technology Sydney (UTS)
16/11/15	Meeting	Concerned community members from Correct Planning and Consultation for Mayfield group (CPCFM), Coal Terminal Action Group (CTAG), Doctors for the Environment
10/12/15	Meeting	Mr Greig Duncan, Hume Coal
15/12/15	Teleconference	Mr David Trench, Griffin Coal
7/3/16	Teleconference	Mr Keiron Rochester, Whitehaven Coal
17/3/16	Meeting	NSW Minerals Council, Glencore Coal Assets, Centennial Coal, , Pacific National, Freightliner, Australian Rail Track Corporation (ARTC), Port Waratah Coal Services (PWCS), Newcastle Coal Infrastructure Group (NCIG), Aurizon (by teleconference)

Table 5: Submissions to the Review

Ref:	Name	Organisation
SUB0001	Nick Higginbotham, PhD	
SUB0002	NSW Minerals Council	NSW Minerals Council
SUB0003	Mr Rick Banyard	
SUB0004	Correct Planning and Consultation for Mayfield group (CPCFM)	Correct Planning and Consultation for Mayfield group (CPCFM)
SUB0005	Correct Planning and Consultation for Mayfield group (CPCFM)	Correct Planning and Consultation for Mayfield group (CPCFM)
SUB0006	Mr Rick Banyard	
SUB0007	Mr Bruce Kingsford	
SUB0008	Correct Planning and Consultation for Mayfield group (CPCFM)	Correct Planning and Consultation for Mayfield group (CPCFM)
SUB0009	Mr Peter Sansom	
SUB0010	Correct Planning and Consultation for Mayfield group (CPCFM)	Correct Planning and Consultation for Mayfield group (CPCFM)
SUB0011	Mr Lindsay Bridge	

APPENDIX 7. BACKGROUND PAPERS COMMISSIONED

Available at http://www.chiefscientist.nsw.gov.au/reports/review-of-rail-coal-dust-emissions

Topic: Sensor and Monitoring Technologies
Terms of Reference 2
Review of rail coal dust emissions management practices in the NSW coal chain

Expert name	Organisation
Professor Benjamin Eggleton	Director, Australian Research Council Centre of Excellence, Centre for Ultrahigh bandwidth Devices for Optical Systems, The University of Sydney
Dr Melita Keywood	Principal Scientist, Earth Health Group, Oceans & Atmosphere, Commonwealth Scientific and Industrial Research Organisation (CSIRO)