Tunnel Air Quality Review
Summary Report

1. Introduction

Since 2014, the Advisory Committee on Tunnel Air Quality (ACTAQ) has released a series of technical reports on road tunnel air quality developed by independent experts and NSW agencies. The reports are available here.

The Minister for Roads requested that the NSW Chief Scientist & Engineer lead a review of these reports, considering recent monitoring data on operating road tunnels in Greater Sydney and the latest information on the health effects of traffic-related air pollution. The Terms of Reference for the review are available here.

The purpose of the review is to provide scientific and technical advice about the potential benefits of installing filtration and air treatment systems in NSW road tunnels.

2. Summary of main findings

The main findings of this review align with previous conclusions and can be summarised as:

- There is increased confidence in the associations between traffic-related air pollution and adverse health effects.
- Air pollution primarily affects health through cardiovascular and respiratory diseases. However, it also impacts metabolic health, neurodevelopment, and childhood development, increasing chronic disease risks later in life.
- There is no safe level of exposure to traffic-related air pollution.
- Governments and regulators must continue to implement and evaluate the effectiveness of measures to reduce exposure to traffic-related air pollution, thereby improving the health and well-being of the population.
- Various air cleaning technologies can effectively remove a significant proportion of particulates, nitrogen dioxide (NO_2), and, in some cases, nitrogen oxides (NO_x) from tunnel air.
- In countries with existing air cleaning technologies (for particles, and in some cases NO_2) designed and used for external air quality management in an urban context, such as Spain, Italy, Norway, Hong Kong and China, the technology is either not used, is used occasionally or is used for very short periods (minutes or perhaps one or two hours per day during the busiest periods of traffic).
- While NO_2 removal systems exist in countries like Spain, Hong Kong, and Mainland China, they are not regularly operated or maintained. NO_x removal technologies are complex and primarily used in Japan.
- In all cases examined by Professor Dix, air-cleaning technology was not installed to meet environmental performance criteria. Professor Dix found that tunnel proponents often use air cleaning technologies to gain public acceptance and project approval.
- Excluding the Sydney Harbour Tunnel and Eastern Distributor, there are 19 operating and under construction motorway tunnel stacks in Sydney. Based on the costs identified in the Dix review, installing air cleaning technologies in these 19 stacks could cost between $855 million and $1.425 billion (using a nominal 1000 m^3/s per stack). This is only the capital cost of the air cleaning equipment and does not include any associated civil works or ongoing operating costs.

- There is no evidence of emissions from tunnel stacks in Sydney significantly impacting ambient air quality.
- The most effective approach for reducing traffic-related air pollutants is at the source through vehicle emission controls.

Consistent with previous advice from the Advisory Committee on Tunnel Air Quality in 2014 and 2018, a review of available evidence shows little to no health benefit for surrounding communities in installing air cleaning technologies in any of Sydney's motorway tunnels.

3. Summary of the three individual components of the Review

This independent review comprised three components:

1. A review of the findings and recommendations of studies and reports on the human health effects of traffic-related air pollution, conducted by Professor Bin Jalaludin (UNSW, Centre for Safe Air).
2. A review of the air quality monitoring data from operating motorway tunnels across the Greater Sydney network and impact on ambient air quality, conducted by Professor David Carslaw (University of York) – including a peer review conducted by Dr Mark Hibberd.
3. Consideration of the effectiveness and relative costs of tunnel filtration and air treatment systems for removing particles, nitrogen dioxides and other pollutants from air emitted from tunnel ventilation outlets, conducted by Professor Arnold Dix (President International Tunnelling and Underground Space Association).

The key elements of each component of the review are summarised below.

3.1. Review of the findings and recommendations of studies and reports on the human health effects of traffic-related air pollution

This independent review assessed recent (last ten years) studies on the health effects of traffic-related air pollution. It discusses the current evidence and its implications for Environmental Impact Statements of recent motorway tunnel projects.

This review was conducted by Professor Bin Jalaludin

In the past 10 to 15 years, there has been continuing research into the health effects of ambient air pollution, resulting in an increasingly robust evidence base. New adverse health effects continue to be identified, and the evidence for robust associations or causality continues to strengthen. The number of studies on this topic has risen. In 2022, the Health Effects Institute released a report on the health effects of long-term exposure to traffic-related air pollution. The 2022 Health Effects Institute report reviewed 353 scientific papers—an increase from 167 reviewed by the Health Effects Institute for its 2010 report.

Confidence in the evidence for associations between traffic-related air pollution and adverse health effects has strengthened. The 2022 report upgraded confidence for five health outcomes and found moderate to high confidence for six additional outcomes not considered in the 2010 report. The U.S. Environmental Protection Agency also upgraded certain health outcomes related to pollution.

More concentration-response functions are now available for health impact assessments—20 additional for particulate matter less than 2.5 microns ($PM_{2.5}$) and 22 for nitrogen dioxide (NO_2) since 2013, covering various health effects, including mortality and respiratory issues.

Air pollution primarily affects health through cardiovascular and respiratory diseases. However, it also impacts metabolic health, neurodevelopment, and childhood development, increasing chronic disease risks later in life. $PM_{2.5,}$ diesel exhaust and vehicle exhaust constituents benzene and formaldehyde are designated as carcinogenic by the International Agency for Research on Cancer.

Strong evidence indicates that $PM_{2.5}$ is linked to cardiovascular effects, respiratory issues, and cancer. Moreover, $PM_{2.5}$ is a modifiable risk factor for dementia and cardiovascular disease, highlighting its significance alongside traditional risk factors like smoking and poor diets.

Air pollution harms health from prenatal stages to old age, with poor childhood conditions leading to chronic diseases later in life. Improved air quality is associated with better lung function in children, illustrating that the harmful effects on lung growth are reversible, which has important implications for respiratory and cardiovascular health in adulthood.

The scientific consensus is that there is no threshold for $PM_{2.5}$ and NO_2 below which adverse health effects do not occur (i.e., there is no "safe" level).

Relative contribution of traffic-related air pollution

In a health impact assessment (HIA) by the New South Wales (NSW) Department of Planning and Environment in the Sydney Greater Metropolitan Region (GMR), man-made sources contributed 48% (3.07 µg/m³) to the population-weighted annual average $PM_{2.5}$ of 6.43 µg/m³. On-road motor vehicles accounted for 17% of this concentration, with exhaust contributing 13% and non-exhaust sources 4%. Wood heaters contributed the most, at 42%.

Approximately 600 premature deaths in NSW each year are linked to these anthropogenic $PM_{2.5}$ sources, costing about $5.02 billion (in 2021 AUD). Specifically, on-road motor vehicles are responsible for around 110 premature deaths annually, costing $913 million.

Implications for past and future motorway tunnel health impact assessments

Previous tunnel health impact assessments focused on limited outcomes, potentially underestimating the impact of air quality changes on health. However, they could be considered to have been conducted according to the known evidence at that time. Future assessments should consider the expanded range of health outcomes supported by recent research.

Implications for operating motorway tunnels

Given:

- there is no safe level of exposure to $PM_{2.5}$ and NO_2,
- on-road motor vehicles account for a moderate to a large proportion of the population-weighted exposure to $PM_{2.5}$ and NO_2, and
- the increasing number of adverse health effects attributable to $PM_{2.5}$ and NO_2,

it is imperative that governments and regulators continue to implement and evaluate the effectiveness of measures to reduce exposure to traffic-related air pollution, to improve the health and well-being of the population.

3.2. Review of the air quality monitoring data from operating motorway tunnels across the Greater Sydney network

This independent review included an analysis of available monitoring data for six operating motorway tunnels in Sydney to determine if any impact from tunnel stack emissions was discernible in the ambient monitoring data.

This review was conducted by Professor David Carslaw.

The amount of ambient air quality data associated with tunnel stacks in Sydney is vast and likely represents the most comprehensive data of its type anywhere in the world. Of specific note is the carefully considered air quality monitoring network design, which adopts smaller networks around each tunnel vent location and covers periods over several years. Moreover, measuring multiple pollutants at each site strengthens any analysis undertaken. This design and its associated data lends itself to detailed and focused analysis to determine whether the emissions from vent stacks have a detectable impact on ambient air quality.

Overall, the review found very little evidence that emissions from tunnel vent stacks have an appreciable impact on nearby air quality for various pollutants, including nitrogen oxides (NO_x) and particulate matter less than 10 microns (PM_{10}). The review found no evidence of emissions from tunnel stacks impacting ambient air quality at any sites other than one site close to the M5 (Jackson), potentially indicating a small tunnel stack impact based on the direction and nature of NO_x concentrations at that site.

At the Jackson site, tunnel vent stack emissions potentially contribute a few per cent (<1ug/m³) to ambient NO_x concentrations. A contribution this low for NO_x would mean that any contribution to PM_{10} or $PM_{2.5}$ would be even lower and essentially undetectable because mass emissions of NO_x from vehicles are much greater than particulates.

3.3. Effectiveness and relative costs of tunnel filtration and air treatment systems for removing particles, nitrogen dioxides and other pollutants from air emitted from tunnel ventilation outlets

This independent review examined international practices for air treatment systems in urban road tunnels. It assessed the effectiveness and costs of filtration systems for removing particles, nitrogen dioxide, and other pollutants from air released by tunnel ventilation outlets.

This review was conducted by Professor Arnold Dix.

This independent review draws upon evidence collected by Professor Dix in the field and remotely about the latest active air cleaning and particle removal projects in Hong Kong, Beijing, Norway, Korea, Italy, Spain, and Tokyo. The Dix report is based on inspections of installed equipment and interviews with key stakeholders from the air cleaning industry, manufacturers and road authorities. Professor Dix conducted confidential field attendances, site inspections, and interviews on projects and their technical advisors, coupled with telephone and internet attendances of key personnel in other countries.

Various air cleaning technologies can effectively remove a significant proportion of particulates, NO_2, and, in some cases, NO_x from tunnel air. There is considerable experience with systems such as electrostatic precipitators and mechanical filtration to remove particulates from tunnel air. While NO_2 removal systems exist in countries like Spain, Hong Kong, and Mainland China, they are not regularly maintained and operated. NO_x removal technologies are complex and primarily used in Japan.

The capital cost for combined particle and NO_x removal is between \$45,000 and \$75,000 per m^3/s. For a hypothetical 1000 m^3/s combined air cleaning station, the capital cost should be between \$45 and \$75 million. This is the capital cost of the air cleaning equipment only, and does not include any associated civil works or ongoing operating costs. All facilities, subcontractors, maintenance contractors and government departments declined to share operating costs with Professor Dix.

The only countries identified and investigated by this study as operating or now installing urban air cleaning technologies were Hong Kong (China), China (Mainland), Spain, and Japan. In the case of China, there was credible evidence that future installation of air cleaning technologies will occur as part of China's 'blue sky' policy in a small number of road tunnels where urban design makes using a ventilation tower extremely undesirable.

In countries with existing air cleaning technologies that are designed and used for external air quality management in an urban context, such as Spain, Italy, Norway, Hong Kong and China, the technology is either not used or is used occasionally or for very short periods (minutes or perhaps one or two hours only).

In Japan, air cleaning technology has been diligently used, its efficiency is continually reported, and the systems are maintained. The challenge is that no agreed criteria exist to turn the systems off. Japan has experienced enormous improvements in its air quality. However, without an agreed air quality threshold, no practical mechanism exists to determine when the cost exceeds the benefit of operating the technology.

There is a universal lack of a 'cost-benefit' analysis of tunnel air cleaning technologies within the published literature. Discussions with countries that do not install the technologies advise that the benefits do not warrant the technology's high economic and environmental costs.

Air cleaning technologies to manage external air quality are usually installed to achieve regulatory approval or political support for a project. Properly designed and operated road tunnels in countries with good ambient air quality generally do not need either PM or NO_x removal technology to manage the risks to human health from tunnel air.

Emission controls on vehicles are the best way to manage air quality concerns, with these controls being a highly effective means of reducing particulate and NO_2/NO_x emissions.

World best practice for tunnel air health risk management is a combination of:
- Vehicle emission controls
- Management of in-tunnel air quality
- Proper design and operation of tunnel air dispersal points such as portals and vertical emissions structures

4. Overview of previous advice and evidence regarding the impact of tunnel stacks on ambient air quality in Sydney

Community groups have raised concerns about major tunnel developments over the years partly because of the potential impacts on air quality from tunnel stack emissions.

In 2018, Dr Ian Longley provided the following independent advice to the Advisory Committee on Tunnel Air Quality regarding tunnel ventilation stacks:

- Road tunnel ventilation stacks work by exploiting the natural mixing of the atmosphere to efficiently disperse air pollutants. This point has been recognised by air quality scientists and pollution engineers for decades, and has led to the widespread adoption of the stack as a means of reducing the impacts of pollutant emissions from many sources.
- Due to the long history of stacks being used to disperse industrial air pollution, there are numerous validated and extensively used atmospheric dispersion models to predict stack impacts. These models are used by regulatory agencies and research communities. These communities collaborate continuously to improve and update these models.
- Experience from previous motorway tunnel projects, both in Sydney and in other areas of the world, has demonstrated that air dispersion modelling for tunnel stacks is robust and conservative, and that tunnel ventilation stack emissions result in nearby residents experiencing little, if any, increase in exposure to vehicle emissions.

The results of comprehensive atmospheric dispersion modelling were presented in the EISs for all road tunnel projects. These results showed that ventilation stack emissions would contribute little, if any, to surrounding residents exposure to vehicle emissions.

For example, for the Western Harbour Tunnel EIS:

- Emissions were modelled from surface roads, ventilation outlets and existing tunnel portals (Sydney Harbour tunnel and Eastern Distributor)
- The contribution of background air quality and emissions from surface roads, ventilation outlets and existing tunnel air quality was predicted at 35,490 locations through sophisticated atmospheric dispersion modelling.
- The analysis predicted a maximum total concentration of annual average $PM_{2.5}$ of 11.69 μg/m^3, a maximum contribution from surface roads of 3.79 μg/m^3, and a maximum contribution from tunnel stacks of 0.18 μg/m^3. The modelled contribution of ventilation outlets to ambient air quality is represented by the black line on top of the chart in Figure 1

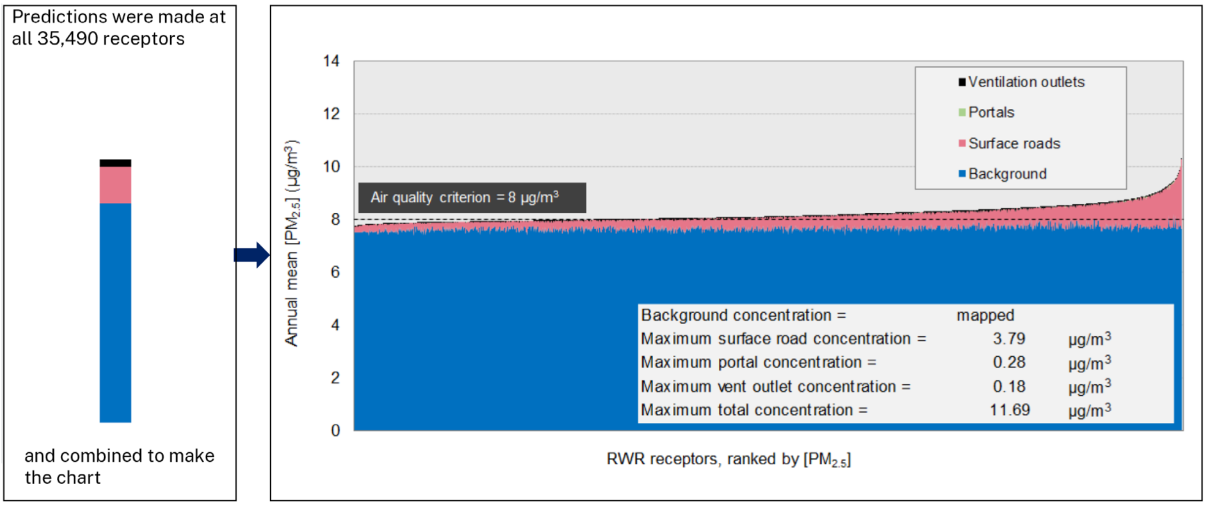

Figure 1 – Relative Contribution of Sources from Western Harbour Tunnel EIS

The black line in Figure 1 can be conceptualised as the maximum benefit of installing air cleaning technology on the tunnel stacks. If air cleaning were 100 per cent effective, the benefit would be an improvement in air quality consistent with removing the black line.

Similar results were presented in every tunnel EIS since the M4 East.

In 2019, Dr Mark Hibberd conducted a study for the Advisory Committee on Tunnel Air Quality that analysed ambient monitoring data for 2009-2013 from sites near the M5 East ventilation stack and for 2005-2006 from sites near the Cross City Tunnel (CCT) ventilation stack to address two questions:

1. What is the potential for a measurable ambient air quality impact from the stack emissions?
2. Are any impacts from stack emissions discernible in the ambient monitoring data?

The analysis demonstrated a small measurable stack impact at CBMS but not at any other M5 East sites (three of which are closer to the stack), nor at any of the CCT sites.

In 2021, Dr Ian Longley prepared a report for WestConnex on changes in local air quality associated with the opening of the M4 East Tunnel. Based on an analysis of ambient air quality monitoring at six sites close to the tunnel route between 1 January 2018 and 12 July 2021, Dr Longley concluded that "there was no detectable impact of the emissions from the ventilation outlets on local air quality".