NSW GOVERNMENT

Advisory Committee
on Tunnel Air Quality

TP06:
Road Tunnel Portal Emissions

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Summary

Venting of tunnel exhaust air via the portals is the norm for tunnels around the world. However, a key operating restriction for recent tunnels in NSW is the requirement for zero portal emissions. This is required by the Minister's Conditions of Approval for the M5 East, Cross City and Lane Cove tunnels. This was initially applied to the M5 East tunnel as a precaution to protect residents around the tunnel portals due to the adoption of a single stack, and was retained for the Cross City tunnel and Lane Cove tunnel.

To achieve zero portal emissions, all tunnel air must be expelled from a stack with air being drawn in at all portals. At the tunnel exit portal, this requires drawing air against its natural direction of flow which is the direction of traffic movement (known as the 'piston effect'). This requirement for 100% stack emissions increases the quantity of ventilation air required to be discharged through the stack, and can significantly increase the size of the stack to be constructed – leading to increased capital costs and visual impacts.

In addition, operation of the ventilation system is required at all times, which also increases the operational cost. However, during periods of low traffic volume, such as during the night, the air quality in the tunnel may be essentially identical to the air quality outside the tunnel. Avoiding portal emissions during these periods is therefore likely to have little or no environmental benefit, but still requires significant energy use (ie will have an associated monetary and environmental cost).

Multiple studies have shown that the detectable impact of portal emissions on local air quality is highly localised to an area within 100–200m of the portal.

1. Scope

Tunnel exhaust air can either be vented from elevated outlets (ie stacks) and/or at ground level from the tunnel portals. This paper (Technical Paper 6) considers portal emissions, whereas Technical Paper 5 covers stack emissions.

2. Why and when portal emissions are used

A road tunnel takes vehicles underground so that their emissions, which would otherwise be released from exhaust pipes over the whole length of a road, are now released into the atmosphere from one or more specific locations in a more concentrated form. For many tunnels - including most short tunnels (of a few hundred metres in length) - the points of release will be the portals. Historically, many longer or busy tunnels, especially those in urban areas, have had stacks to increase ventilation capacity. However, even when stacks are present a portion of the tunnel exhaust air will be released via the portals, unless a ventilation design to avoid portal emissions is adopted. Portal emissions are the norm for road tunnels overseas, including in several cities with large numbers of road tunnels (eg Stockholm, Oslo, Madrid and Hong Kong).

Historically, stacks have generally been used for tunnels longer than 2km to provide jurisdictions with confidence that the criteria for both in-tunnel and outdoor air quality are met.

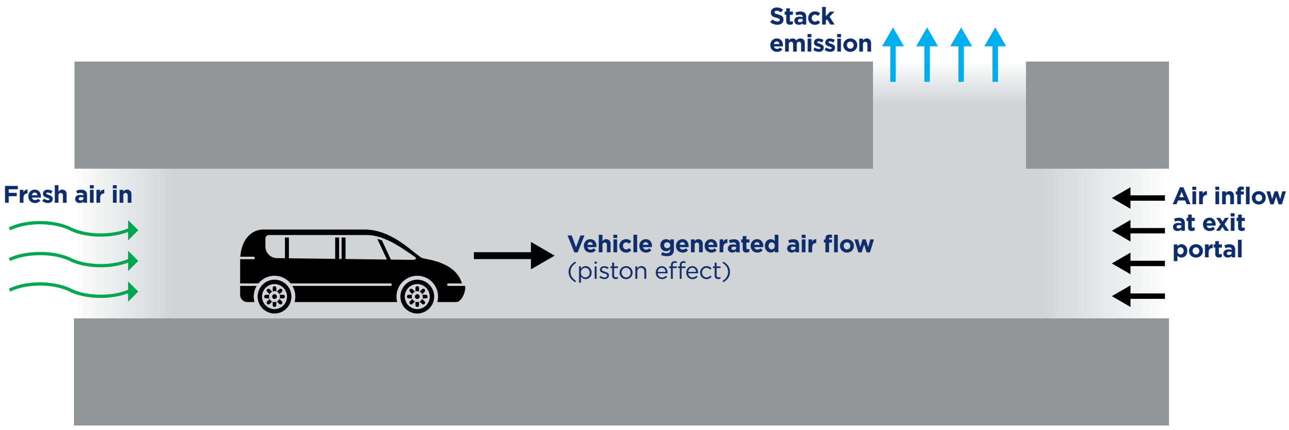
Reductions in vehicle emissions over the last few decades have meant that the need for ventilation stacks has diminished. In many cases overseas it has become possible to meet both in-tunnel and outdoor air quality requirements using portal emissions alone for some or all of the time. Furthermore, avoiding excessive ventilation is desirable from the point of view of energy efficiency. For instance, the semi-rural Hafnerburg tunnel on Zurich's busy by-pass had stacks removed from its design, and nearby on the same motorway the stacks for the new third tube of the 3.3 km-long Gubrist tunnel are expected to be used for fire emergency use only. Both the 2.5 km-long Roer tunnel in the Netherlands and Hong Kong's busy 1.2 km-long Nam Wan tunnel both opened in 2009 without stacks.

One of the potential advantages of road tunnels relative to surface roads is the opportunity to deliberately site portals so that emissions in densely populated residential areas are avoided. In some cases tunnels have been extended so as to relocate the portals beyond sensitive receptors and retain portal emissions (eg Central Kowloon tunnel, Hong Kong) and avoid incurring the cost of introducing stacks (eg Roermond tunnel, Netherlands). However, in many cases it can be exceedingly challenging to find suitable locations in urban areas that combine an absence of sensitive locations (which can be protected against development pressure into the future) and assured favourable dispersion under all meteorological conditions.

In Australia, several tunnels have been designed to meet a 'zero portal emission' condition. This is required by the Minister's Conditions of Approval for the M5 East, Cross City and Lane Cove tunnels. This was initially applied to the M5 East tunnel as a precaution to protect residents around the tunnel portals, and was retained for the Cross City tunnel and Lane Cove tunnel (Technical Paper 4: Road Tunnel ventilation Systems).

Zero portal emissions are achieved by drawing emissions away from the exit portals against the flow of air that is induced by the traffic (known as the 'piston effect'), so that all polluted air is removed via the stacks. This also increases the quantity of ventilation air required to be discharged through the stack, and can significantly increase the size of the stack to be constructed – leading to increased capital cost and visual impacts.

Figure 1: Illustration showing tunnel air flow direction to avoid portal emissions



In addition, operation of the ventilation system is required at all times, which also increases the operational cost and energy use. However, during periods of low traffic volume, such as during the night, air quality in the tunnel may be essentially identical to the air quality outside the tunnel. Avoiding portal emissions during these periods is therefore likely to have little or no environmental benefit, but still requires significant energy use (ie will have an associated monetary and environmental cost).

Ventilation control systems or protocols have been adopted at some tunnels to manage portal emissions. Approaches have included a time schedule that regulates portal emissions to only occur at certain times of the day, for example when there are low traffic levels. Such an approach has recently been implemented in the Melbourne City Link tunnels (Transurban, 2012). Systems that regulate portal emissions based on in-tunnel or external air quality levels are rare.

3. Predicting and assessing the impact of portal emissions

An important consideration in managing portal emissions is the possibility that such emissions (which are generally required to maintain acceptable air quality inside the tunnel) will lead to a breach of ambient (outdoor) air quality standards (or other performance-based air quality consent conditions) outside the tunnel. Maintaining such a balance is more critical in a location where outdoor air quality is close to, or already breaches, local air quality standards.

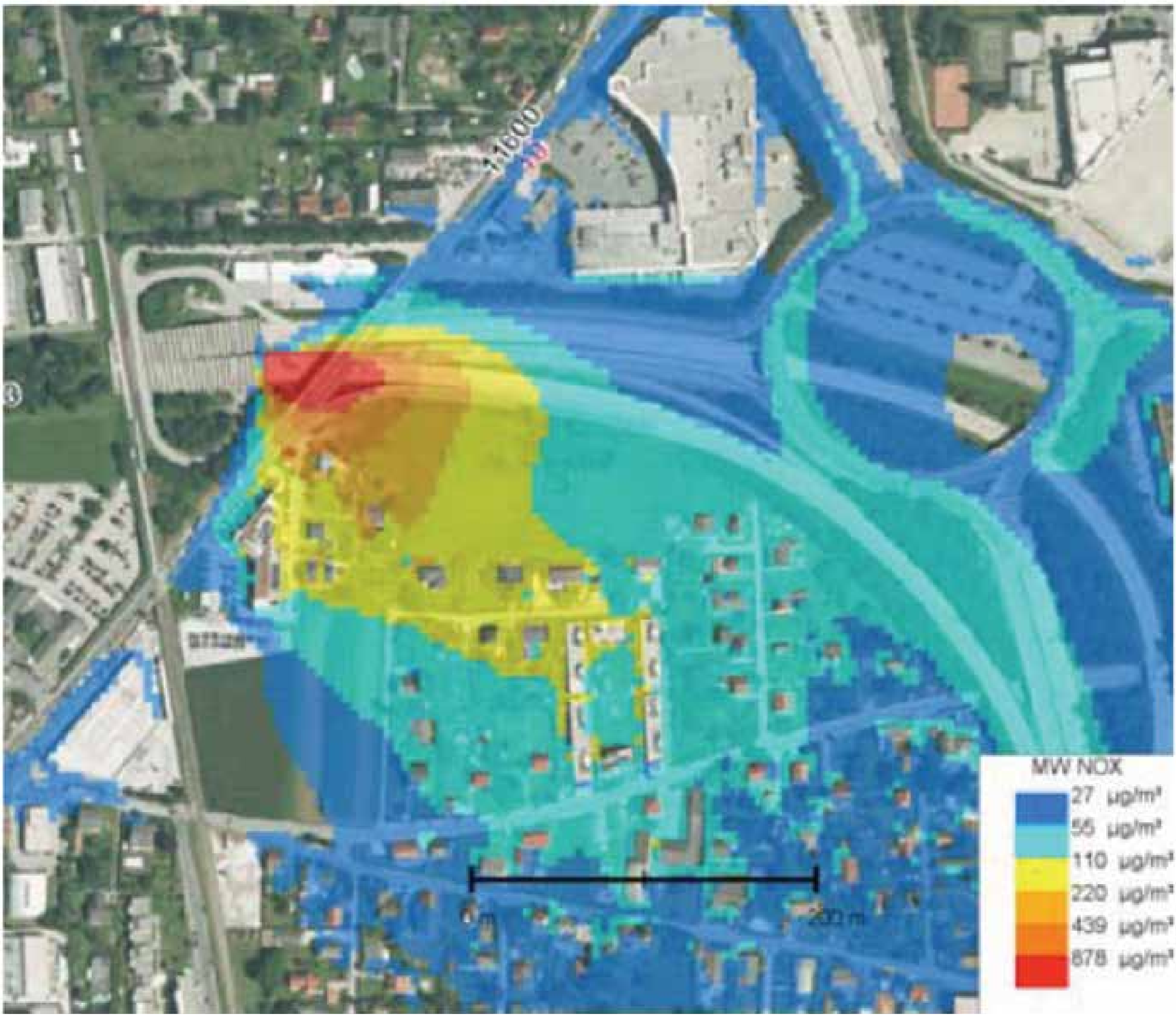
Our understanding of the impact of portal emissions on ambient air quality comes from four types of evidence: computer modelling, wind-tunnel modelling, tracer-release experiments and air quality monitoring. Results from each of these approaches are broadly consistent. The key characteristic of portal emissions is rapid and effective dispersion, reducing concentrations to background levels over relatively short distances. More specific key findings are:

1. Air exits the portal as a relatively fast-moving plume, but rapidly mixes with the ambient air.
2. In the immediate vicinity (about 10m) of the portal, air quality can be substantially worsened with the potential to exceed ambient air quality guidelines. However, the affected zone is normally limited to the roadway (McCrae et al., 2009, COB, 2009, Kuschel & Wickham, 2013).
3. Away from the immediate vicinity of the portal, concentrations of pollutants decrease rapidly, especially moving away from the roadway. The impact of portal emissions on roadside concentrations typically only extends up to about 100–200m from the portal (McCrae et al., 2009, Kuschel & Wickham, 2013). Beyond this distance, it is difficult to distinguish the impact of the portal from the surface road section (Brousse et al., 2005).
4. If the roadway is in a trench or cutting as it enters the portal, or is otherwise separated from the surroundings, the elevated concentrations can persist in the trench to larger distances from the portal, but locations to either side of the road will be afforded extra protection as lateral dispersion of pollutants is constrained (Brousse et al., 2005, COB, 2009).
5. There is generally little or no impact of portal emissions on the land above where the tunnel goes underground (Brousse et al., 2005).

Small variations from these general findings may arise because of differences in local wind patterns, and because dispersion can be improved or reduced by the surrounding topography and the design of the portal and connecting roads. The shape of the zone within which pollutant concentrations are measurably increased can be steered in the direction of locally prevailing winds (an example is shown in Figure 2). In the presence of dense or tall buildings the flow of air might be diverted in a way that may distort the shape of the portal plume in ways that can be modelled by computer or wind-tunnel, but with some uncertainty.

Modelling and physical principles indicate that nitrogen dioxide (NO_2), being a secondary pollutant, produces portal plumes that differ from those of other pollutants. This is because extra NO_2 may be formed when tunnel exhaust air mixes with background air (through the reaction of nitric oxide (NO) from the tunnel with ozone in ambient air).

Figure 2: Example of modelled impact of a tunnel portal on concentrations of oxides of nitrogen (NO_x).



The red colour indicates the polluted portal plume which is rapidly diluted to lower concentrations (blue) as the plume mixes with outdoor air. This portal is impacted by prevailing northerly winds which deflect the portal plume towards the south as it dilutes. Light blue areas to the right of the image indicate areas impacted by emissions on surface road sections as well as the portal. From Oettl et al. (2013).

3. Predicting and assessing the impact of portal emissions

The general suite of dispersion models used for the calculation of impacts of surface roads is of limited suitability for all but the simplest of tunnel portals. These models are not designed to model dispersion involving the characteristic features of portals such as sunken roadways, vertical walls, the air turbulence and flow created by vehicles moving in a tunnel, and the way a portal plume mixes with background air.

However, two models have been developed specifically for tunnel portals. These models are based upon, and validated against, monitored data from real tunnel portals, including tracer release experiments. The more commonly used and better documented (in English) is the GRAL model developed at the Graz University of Technology (Oettl et al., 2002, 2005, Oettl, 2013). This model is dependent upon finely detailed input data on terrain and built topography, as well as two empirical parameters that need to be determined independently for each tunnel. The alternative model is the one developed by the Japanese Highway Public Corporation (Okamoto et al., 1998).

Due to the limitations of computer modelling, some tunnel projects have employed scale modelling, particularly in the wind tunnel. For example, the urban Central Artery Tunnel project in Boston was considered too complex, with portals set amongst complex arrays of tall buildings, to rely on computer modelling. A 1:100 scale model was built with moving model vehicles on a conveyor belt to simulate the traffic-induced air flow (Schattanek & Wan, 1996).

4. Monitoring portal emissions

It is challenging to measure the impact of portal emissions on air quality directly because portals are always associated with the surface road leading from the portal. Except in the immediate vicinity of the portal, it is very difficult to distinguish the portal emissions from the surface road emissions, especially in an urban area where there are often other nearby roads or emission sources. A further challenge is presented by the rapid dilution of the portal plume, which means that a study based on only one, or a few monitoring sites risks being located outside the zone of impact (and logistical considerations often place limitations on what sites can be monitored) (Oettl, 2013, Longley et al., 2014).

Studies which measure air quality around road tunnel portals are relatively rare, but the key ones are listed in Table 1. There are no studies in the literature which compare measured air quality around a portal before and after the opening of a tunnel.

The most comprehensive studies to date are those at the semi-rural Bell Common and Southwick tunnels in the UK (McCrae et al., 2009). These studies confirmed a strong decay in concentrations within 50–100m of the portals, and that NO_2 concentrations extended slightly further than other pollutants. Portal emissions at these tunnels were also investigated using the GRAL model.

The studies at the Landy Tunnel in Paris and the Wijkertunnel in the Netherlands are important in demonstrating the 'trench' effect. At the Landy Tunnel higher concentrations of NO_2 were observed about 250m from the portal than at < 100m from the portal, although much lower than within a few metres of the portal. This was almost certainly due to the very busy motorway emerging from a trench between the 100m and 250m distances. Furthermore, the high concentrations at 250m were similar to those measured at a monitoring site alongside a surface section of the same motorway about 2km to the north. This suggests that the concentrations observed around 250m from the portal were caused, or at least dominated by, the surface road and not substantially influenced by the portal. The Wijkertunnel study further confirmed this trench effect through the somewhat counter-intuitive result that higher concentrations of NO_2 were observed at 100m from the portal where the road emerged from a cutting, than at closer distances, due to the partial 'protection' provided by the trench.

4. Monitoring portal emissions

Table 1: Previous observational studies of road tunnel portal emissions

Tunnel	Location	Tunnel length (m)	Annual average daily traffic (both directions)	Environment	Method	Reference
Valerenga	Oslo	700	65,000	Urban	Tracer gas release	Larssen et al, 1990
Ehrentalerberg	Austria	3 500	15,000	Semi-rural	Tracer gas release	Oettl et al, 2002
Landy	Paris	1 360	220,000	Urban	Hydraulic model; 10 sampling sites	Brousse et al, 2005
Kaisermuehlentunnel	Vienna	2 150	90,000	Urban	5 monitors	Oettl et al 2005
M5 East	Sydney	4 000	95,000	Urban	Single monitors at each portal	Holmes Air Sciences, 2006
Southwick	UK	490	42,000	Semi-rural	30 sampling sites	McCrae et al., 2009
Bell Common	UK	470	103,000	Semi-rural	30 sampling sites	McCrae et al., 2009
Wijkertunnel	Netherlands	680	53,000	Semi-rural	14 sampling sites	COB, 2009
Johnstone's Hill	Auckland	380	15,000	Rural	10 sampling sites (5 per portal)	Kuschel & Wickham, 2013
Plabutsch	Graz, Austria	10 000	18,800	Urban	Single monitor	Oettl, 2013
Victoria Park	Auckland	440	54,000	Urban	7 sampling sites	Longley et al., 2014

5. Key requirements for modelling and monitoring of portal emissions

5.1. Understanding baseline conditions

Experience has indicated that where performance-based criteria (such as air quality standards or equivalents) are likely to be put in place, an understanding of the baseline (existing) air quality is important. A general indication of baseline air quality within the city or suburb ('urban background') is usually available from regulatory monitoring in Australian cities, but these data will not provide information on the localised concentrations which can be substantial around tunnel portals. This is because portals are often located in areas of existing high traffic levels. If a tunnel project also involves construction of additional surface roads or attracts additional traffic (especially heavy-duty diesels) to the area, it may raise baseline air quality above the general urban background. This can be compounded further if vehicles are likely to be climbing or accelerating in the area. However, the tunnel may also substantially remove or alleviate surface traffic and congestion, thus locally reducing baseline air quality.

For example, three road tunnels were built in Oslo (opening between 1989 and 2000) to reduce congestion and other detrimental effects of traffic within populated areas (TØI, 2004). The result was a general reduction in concentration of traffic-related pollutants due to a reduction in surface traffic. However, the exception was in the immediate area of the portals. Here, redistribution of traffic led to the formation of (previously absent) queues of traffic accessing the tunnels. Hence, the localised adverse effect was due to the redistribution of traffic caused by the presence of the tunnels, rather than the tunnels themselves. On the other hand if the pre-tunnel site of the portals was a major road junction with congestion and queuing traffic which was relieved by the tunnel, baseline conditions may be mitigated and post-opening air quality may be improved, even with the addition of portal emissions.

5.2. Pre-opening monitoring

Tunnel portal emission management can be aided by the collection of the following data:

a) Long-term (approximately 1 year) meteorological data (particularly wind speed and direction) in a location representative of airflow (ie unsheltered or overlooked) around the portal.

b) Spatial variation in baseline air quality around the portal zone, especially focussing on sensitive receptors and aiming to capture the impact of existing surface roads. The precise locations, numbers and density of air monitors should be informed by, and intended to capture, the anticipated change in air quality. This data not only informs any assessment, but can also be used to validate modelling of baseline air quality.

c) Continuous monitoring of NO, NO_2 and (ideally) ozone near the portal site. The risk of high values of NO_2 is partly dependent upon the background levels of all three compounds in the atmosphere.

d) Successful dispersion modelling is dependent upon accurately specified emission factors for traffic in the tunnel. Emission factors can be indirectly measured in existing tunnels using well-established methods, ideally in tunnels with a combination of moderate-high concentrations, vehicle identification systems (such as from tolling systems) and well-constrained air flow.

e) Detailed traffic data (including heavy-duty vehicles) for existing roads near the portal (and modelled data for post-opening) are very valuable due to the significant impact of emissions from these roads and the desire to separate these impacts from those of the portal.

5. Key requirements for modelling and monitoring of portal emissions

5.3. Post-opening monitoring

Once a road tunnel with portal emissions is open and operating, post-opening air quality monitoring may be conducted for the purposes of :

a) compliance with approval conditions,

b) adjustment to any management protocols (such as ventilation settings),

c) validation (and adjustment if necessary) of any dispersion modelling, such that modelling can henceforth potentially replace the monitoring and/or be used as an input to active ventilation management,

d) confirm locations of peak impacts,

e) satisfy all parties that there is no external air quality issue related to the tunnel.

Monitoring should anticipate any potential ‘trenching effect’ and monitor siting informed by suitable atmospheric dispersion modelling.

6. Further information

For further information related to this topic please see:

Technical Paper 4	*Road tunnel ventilation systems*
Technical Paper 5	*Road tunnel stack emissions*
Technical Paper 7	*Options for reducing in-service vehicle emissions*
Technical Paper 11	*Criteria for in-tunnel and ambient air quality*

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