MANAGING AIR OUTSIDE OF TUNNELS:

CONTRACT NO. 6400/3003

REPORT FOR THE RIJKSWATERSTAAT DEPARTMENT OF ROAD AND HYDRAULIC ENGINEERING, THE NETHERLANDS

- 1 MARCH 2006

Stack at Tokyo Bay Tunnel, Japan

By Arnold Dix

Counsel – at – law

Adj. Prof Engineering, QUT

Email: counsel@arnolddix.com

Ph: +61 (0) 419 688 890

Table of Contents

1. Introduction

Motor vehicles which are propelled by internal combustion engines necessarily produce pollutant combustion emissions. All vehicles produce particulates from braking systems, tyres and other mechanical interfaces. Both combustion products and non combustion products have been demonstrated to adversely effect the environment and human health.

Advances in the technologies employed for both fuel production and internal combustion engine processes have changed the amount and composition of combustion products.

The construction of road tunnels in urban environment necessarily changes the distribution of the motor vehicle emissions and the concentrations at which these emissions occur in both time and geographic location.

In Europe redistribution of vehicle contaminants is traditionally to the portal areas of transverse, semi transverse and longitudinally ventilated tunnels with a small number of notable exceptions from more recent tunnels constructed in Norway, Germany, France, Italy, Austria and soon Spain.

In Asia the trend has likewise been to portal emissions but with the recent development of vertical distribution towers. Eg. Japan, Taiwan, Korea and Australia.

Amongst those contaminants emitted from motor vehicles the particulate (PM) proportion and the NO_2 components have long been identified as being potentially harmful to human health.

Epidemiological studies have concluded that there is no threshold limit for the occurrence of human health effects following exposure to some of these components of vehicle emissions such as particles.

There are a range of techniques commonly used around the world to ensure that emissions from tunnels are appropriately dealt with from an environmental and health perspective.

These techniques typically relate to both the rates of contaminant generation by vehicles and the appropriate management of the emitted materials.

Techniques range from carefully locating tunnels and their tunnel air emission points – to regulatory factors such as fuel composition, emission controls, traffic speeds and differential tolling.

Once contaminants are generated a range of measures including portal dispersion, slots, stacks and even pollution removal technology are available to manage the effect of tunnel contaminants upon the environment.

Because motor vehicle contaminants are a normal component of human exposure in both urban and rural environments there is a substantive debate about the effort which should be taken in the context of spending limited funds on air cleaning technologies which address at best local issues associated with the redistribution of pollutants – often instead of focusing on lowering the exposure to the general community to the contaminants.

Balancing these two approaches to containment management demands clear articulation of air quality objectives to be achieved coupled with detailed analysis of each tunnel project on its health and environmental context.

A tunnel in an area subject to poor vertical atmospheric mixing, high ambient pollution levels in a valley may need air cleaning technologies because air quality objectives could otherwise not be met.

From a scientific perspective this has meant that detailed computational modelling of the consequences of air cleaning for people outside tunnels (with respect to their exposure to contaminants generated within tunnels) often concludes that there is no net improvement to the exposure levels to human beings if such technologies are installed – even if they are at 100% efficiency (removing all of the contaminants) because the background levels of contaminants 'swamp' any benefit achieved by filtering the comparatively small volume of air released from a tunnel.

This highlights the fact that tunnels are part of a road network – a network which generates contaminants along its entirety – and tunnels are usually just a small component of that network.

Ensuring objective human and environmental contaminant exposure performance is achieved is a fundamental component of the tunnel ventilation system design. This may require a range of design and operation measures including tolling, the redesign or even re-location of dispersal points and/or management of the human and environmental receptors.

There are several current areas of interest in the analysis of likely emissions from tunnels.

Firstly there are a range of new emissions standards which apply to new Dutch vehicles. These will have an effect on the emission rates for particles and some gases.

Secondly it is essential that the peculiarities of the Dutch vehicle fleet be carefully considered when computing likely emission levels. Variations from overseas experience on such matters due to the age and type of the vehicle fleet, fuels and vehicle mix and use may lead to different emission rates than suggested within non nation specific publications, such as the PIARC documentation.

Independently of the scientific evidence which demonstrates the often minimal effect of such technologies where ventilation systems are appropriately designed, there is sometimes a perception of a political advantage in installing these technologies for two reasons.

1. It provides the community with reassurance about the possibility of an adverse change to pollution levels; and

2. It is considered philosophically justifiable on the basis that proven reliable technologies exist and therefore should be used.

Recently these perceived political benefit created severe political problems for an Australian state government when a subsequent decision had to be made not to proceed with the technology on scientific grounds despite the political assurances that it would be installed.

In Australia these issues have been most vigorously raised during the CityLink environmental emission licencing project (in which the author represented the interests of the tunnel designer and constructor, Transfield/Obayashi as legal counsel) and on the M5East tunnel project (in which the author facilitated the public inquiry which dealt with the social and political consequences of community concern with respect to health). The report from the public inquiry in June 2000 – "*International Workshop into Tunnel Ventilation"* and supporting documentation can be viewed at Appendix J of this report.

In February 2000 the author wrote a report entitled *'An international perspective on current pollution dispersal methodologies*'. This report can be viewed at Appendix I and provides some background information as to where world thinking was on the subject of electrostatic precipitators as at 2000.

In addition the author is a delegate on Motor Vehicles and Environmental Emissions to PIARC (which sets a standard for such matters) and has provided briefing reports on the progress of such technologies on a yearly basis since the late 1990's to interested clients.

The author has maintained a watching brief over techniques and technology to manage outside tunnel air quality which has necessarily included ongoing attendances in Europe and Asia to monitor the development of these technologies, most recently resulting in attendances in Europe (Austria) and Japan in April and May 2004, and Italy in 2005.

An inspection of the latest Japanese technology is scheduled for March 2006 and an inspection is scheduled for May 2006 to inspect a new electrostatic precipitator technology during its commissioning phase in Italy.

This briefing document provides an overview of the findings of this investigation up until February 2006.

2. Methodology

In order to provide as up-to-date report on current practices for managing external air quality a two stage approach has been undertaken.

1. Review existing information on techniques and technologies
2. Contact key manufacturers of technologies for technical updates.

The information review was conducted by reviewing literature and memoirs, inspection, and reports in hand.

As at the date of finalizing this report the author has scheduled further inspections in Japan for later in March 2006. In the event that these inspections reveal any significant changes in the performance or use of air cleaning technologies an addendum to this report will be produced.

3. Managing air outside tunnels

Motor vehicle emissions from internal combustion engines have adverse effects on human health and the environment. Because road tunnels redistribute motor vehicle emissions management of the health and environmental impacts of a road tunnel is a core objective of responsible tunnel design.

Clearly articulated air quality requirements are central to optimizing tunnel ventilation design. Without air quality performance objectives there is no engineering basis for determining when air outside a tunnel is managed appropriately.

Air cleaning technologies are but one of the many tools available to meet such requirements. At present only particulate removal and to a limited extent NO removal has been used for external air quality management of road tunnel emissions.

A range of techniques are available during the design, operation and refurbishment stages of a road tunnel to manage outside air quality by optimizing the management of collected emissions from within the tunnel.

These air quality benefits and engineering opportunities continue as emissions change over the life of a tunnel.

Most tunnel designs contemplate changes in air quality management regimes over the design life of the tunnel incorporating features such as, room for air cleaning technologies, increased stack heights (eg. Australia: Melbourne City Link) and increased ventilation power (e.g. Austria: Graz city tunnel). There are also instances were systems have been upgraded to deal with air quality issues such as retrospectively installing particle cleaning technologies. (eg. Japan Ten-nohzan Tunnel)

Management of emitted tunnel air via dispersal techniques is overwhelmingly the most popular technique used around the world. The vast majority of all the World's tunnels rely upon portal emission dispersion. In order to ensure appropriate air quality proximate to tunnels, emissions release via air stacks may in some circumstances be necessary. Mathematical tools are typically used during the planning phase in order to quantify the impact of the pollution and to improve the tunnel and/or ventilation design if required. The actual performance of the systems is frequently monitored after the tunnels become operational.

Dispersion uses a range of techniques to ensure that the emissions from vehicles are thoroughly mixed with such high volumes of outside air that environmental objectives (eg. air quality standards) are achieved or at least not negatively affected. Dispersion techniques provide a superior environmental outcome to any surface roads emissions.

Sophisticated modeling is used to assist in the optimization of the environmental performance of portal emissions from tunnels.

Another approach is to remove components of the vehicle emissions from tunnel air.

Removal of particulates has a long been used to help maintain viability in the tunnel where obtaining an outside air supply is problematic.

Particulate removal for external air quality objectives is rare – but in recent years has been adopted in several tunnels (Japan, Norway, soon Italy and Spain) in areas where ambient air quality is regarded as poor – and dispersion techniques are considered insufficient (or perceived to be inefficient) to achieve air quality objectives.

As an overview external Air Quality can be managed through any combination of measures including:

- *Strategic planning*

  - Proximity to urban areas
  - Proximity to air quality sensitive activities
  - Relationship of the tunnel and adjacent road to meteorological conditions

- *Contaminant Dispersion Techniques*
  - Location of the dispersion points (tunnel portal, gaps, stacks etc)
  - Road geometry and alignment
  - Ventilation design
  - Ventilation operation (dilution)

- *Contaminant Removal Technology*
  - Removal of Small Particles
  - Removal of NOx, NO2

- *Regulation of Traffic Use*
  - Allowance of type of vehicles
  - Time of use
  - Tolling
  - Traffic management to reduce capacity
  - Lowering allowed traffic speed
  - Improve driving behavior

- *Operational aspects of the tunnel*
  - Cleaning the tunnel regularly avoiding high concentrations of small particles
  - Control ventilation capacity

Other measures – still under study – include:

  - Using de-ionising detergent on cladding of walls and ceiling, thereby avoiding the accumulation of fine particles on the treated surfaces
  - Using dust adherent liquid on the road surface, forming a film which captures small particles on the road surface (the remaining road friction should be examined)

The most applicable measures should be chosen by examining the effects on:

- Air quality in the neighborhood of the tunnel
- Individual impact both inside and outside the tunnel

Of the many thousands of tunnels in the world only a small proportion (estimated at <1%) have vertical air dispersion (stacks) and only <0.01% (as estimated) have contaminant removal technologies to extract pollution from the ventilated tunnel air.

3.1 Air Cleaning Technologies

Recent refinements of existing electrostatic precipitation technology in both Japan and Europe suggest that filtration is becoming more readily accepted as a tool for managing tunnel air particulate emissions. These refinements of air cleaning technology promise more efficient, cost effective and reliable technologies to clean particulates from air than were previously available.

Interestingly no data is publicly available on the actual impact on external air quality of such systems. Analysis suggests the impact will be minor (if detectable at all) because emissions from the surrounding surface road network will swamp any improvements made to the small volume of tunnel air being emitted.

The removal of the NO_2 component of vitiated tunnel air is also the subject of ongoing international research. It is concluded from the author's investigations to date (March 2006) that these technologies are not yet mature enough for large scale long term installation and use.

Notwithstanding that tunnel air cleaning technologies are now available a decision to introduce them is often not justifiable on solely health and environmental benefit grounds. Properly designed ventilation systems for the dispersal of air captured within a road tunnel and/or an appropriate operational regime will in most circumstances appropriately disperses pollutants so as to ensure they meet objective air quality criteria.

In most circumstances the emissions from tunnels do not warrant engineered 'extraction' of pollution components because of the low concentrations of discharged materials and the fact that they are a small component of a polluting road network. Better environmental outcomes are often thought to be achieved by addressing the emissions at source via fuel and vehicle emission control regulation of the vehicle fleet.

Nonetheless road administrations in Norway, Japan, Italy and most recently Spain, have chosen to introduce these technologies where the special circumstances of a location warrant 'air cleaning'. The rationale for this varies from project to project but inevitably relates to the special air quality and meteorological circumstances of a particular location (either from a scientific or political perspective) coupled with philosophical and political expediency to:

a. be seen locally as doing the 'right thing';
b. respond to peculiarities in the local environment (meteorology, air quality etc);
c. ensure minimum disruption during the approval development and operation of a road tunnel (minimise disruptive measures against project);
d. accord with a general philosophical objective of reducing emissions to the environment.

The emissions from internal combustion engines are likely to require management for the foreseeable future; perhaps until the technologies which propel our motor vehicles embraces alternative technologies such as hydrogen or fuel cell based technologies.

The appropriateness of spending limited resources on technologies to filter tunnel air which do not result in any measurable improvement in air quality for a city's citizens is a matter of political and moral choice. Other environmental issues are relevant in this regard including the effects of the generation of the energy necessary to run the equipment, greenhouse impacts, and the consequences of concentrating the waste streams by using the technologies.

3.2 Objective Analysis of Tunnel Air Management Options

The most complex air quality questions arise when conducting an objective analysis of the environmental impact of various tunnel air management options for each tunnel proposal.

Important social justice issues with respect to the pollution burden of tunnel discharges may also arise. Almost inevitably those people whom most benefit from the tunnel do not live near it (which is not surprising given they are part of a transport network) yet for local people the burden of air quality change is localized.

It is this ‘benefit’ versus ‘burden’ analysis which is often at the heart of a debate about air cleaning options

The more complex questions then arise with respect to air quality about the equity of any air quality change as a result of the projects use.

If a tunnel project does not proceed there will be a difference in air quality. Understanding the different air quality effects a range of transportation options may cause often forms part of the decision making process for determining the most appropriate transportation option. In some circumstances a tunnel may not be the most appropriate tunnel environmental solution.

In the vast majority of cases it has been demonstrated that tunnels provide a superior environmental outcome to surface roads. Local to the project (and the tunnel air emission locations) – air quality may also change. Managing these local air quality changes is an important part of the tunnel design.

Balancing the legitimate expectations of people and the environment local to a tunnel with the benefits enjoyed by the broad community of the project is complex – and air cleaning technologies are but one of the many means by what they can be seen to be equitably managed.

The recent decisions by the local authorities in both Italy and Spain to purchase electrostatic air cleaning technology will be the first time (in the last ten years) such external air quality environmental issues have driven project in continental Europe. The Norwegians have been using such technologies for the last 10 years in order to test the technologies and facilitate the development of tunnel projects in Norway.

It is likely that following the recent EU Directive on fire and life safety the major European countries will view any proposed focus on environmental emissions as an unwelcome addition to an already onerous European Union tunnel refurbishment program.

Recent examples of the use of external air quality systems in urbanised Japan for philosophical and external air quality reasons suggests a shift in the reasons considered appropriate to use these technologies.

This report is an assessment of material and information gained over the last decade on the management of air emitted from tunnels. It is intended that this information will provide assistance to those people charged with making decisions about the future design and use of road tunnels and road networks.

4. The Technical Investigation

Since the 1990's a watching brief has been held over the development of techniques and technologies for managing the effects on the environment of tunnel air around the world. This has necessarily involved recurrent visits to Norway (where air cleaning technologies are routinely installed), Austria (where an innovative particulate air cleaning technology has been under development), Germany (where innovative air cleaning technologies have been under development), Japan (where not only have innovative air cleaning technologies been under development but like Norway they have been utilised in many road tunnels for external air quality purposes), Italy (who will soon commission their first electrostatic precipitators) and Spain.

Other countries have been investigated including Korea where these technologies have been employed for various purposes. In addition there have been attendances on non tunnel air cleaning related facilities which deal with high volumes of air which must be treated, such as those used traditionally in coal fired power stations.

4.1 Hours of operation of air cleaning technology

In both Norway and Japan the operation of air cleaning technologies is on an as needs basis. The 'needs' are determined in Japan by actual air measurements, while in Norway it is usually on a time clock which corresponds with peak hour traffic.

This is not surprising as the net effect of the technology (coupled with its effectiveness) dictates that the technology is best used when air quality is at its worst and hence the benefit is greatest.

For example in the Kan'etsu (Japan) tunnel EP's operate on average 143 hours per month (this is about 20% of total hours) in the northbound tunnel and 40 hours per month (about 3% of total hours) in the southbound tunnel. In the Tokyo Aqualine tunnel, EP's operate only 12 to 13 hours per year (about 0.15% of total hours).

The inspections and investigations conducted in the course of preparation of this report indicate that electrostatic precipitators designed for external air quality purposes were run for much longer periods than those used for in tunnel visibility. In particular the tunnel inspected in Kobe (built subsequently to the earthquakes which destroyed the city) is operated for much longer periods of time as a direct result of concern expressed by local residents as to their health.

4.2 Austria

An Austrian company has been developing particulate cleaning technologies over the last decade or so. The company specialises in industrial air cleaning for high technology welding and fabrication environments.

For example it is responsible for air cleaning technologies in the Smart, Mercedes and Audi manufacturing sites in the German speaking world. The principal of this company has refined the technology to a point where its performance compares extremely favourably with that of the Japanese manufacturers.

Of particular note is the fact that this company retained the services of the technical university in Graz (the technical university of the internal combustion engine) which specialises in optimisation of internal combustion engine performance, more particularly this university is famous for its pioneering work on diesel soot emissions and the relationships between vehicle speed, internal combustion engine type and pollution emission.

The results of this independent analysis of the Austrian technology can be viewed at Appendix D.

This technology is being installed into the Cessena (Italy) project and is expected to commence commissioning in late May 2006.

Important features of this technology are:

- It is comparatively cost effective
- It produces no liquid waste streams (has a continual filter medium system)
- It is of apparently robust design
- It is of a novel technology not being a refinement of the traditional highly charged electrostatic plate technology but an alternative electrostatically charged filter type
- It uses comparatively low power consumptions
- It has a comparatively low pressure loss characteristic
- It can be coupled to NO_2 cleaning technologies

Particulars of the technology are contained in Appendix A.

4.3 Japan

There are 8,000 road tunnels in Japan with an approximate combined length of around 2,500 kilometres.

Ambient air quality

As noted in the report 'Electrostatic precipitators and ventilation in road tunnels in Japan' of 10 October 2003:

> *Japan is a densely populated, heavily industrialised country with poorer air quality than Australia. Extensive areas of the major cities are covered by thick photochemical smog and, in some areas, brown haze, primarily from motor vehicles and industry. Measures by the Japanese government to address ambient air quality include tough new laws requiring a reduction in particulate matter and NO2 emissions from vehicles. Under the new laws, vehicles that do comply with the standards will need to be replaced or be*

> *fitted with particle filters. It is estimated that about 2.2 million trucks, 300,000 buses and one million diesel powered cars will need to be replaced over several years'.*

The introduction of these new laws has been postponed however in areas such as the Tokyo metropolitan region the new standards have been applied. Indeed the effect of these laws is that now within the Tokyo region there has been a significant improvement in air quality because diesel vehicles (unless fitted with these technologies) are effectively banned. The Japanese being for the most part law abiding citizens comply with such laws.

From inspections of tunnels throughout Japan and discussions with road officials the most common reason for the introduction of air cleaning technologies in tunnels is to maintain visibility. However over the last 3 years several tunnels have been fitted with electrostatic precipitator technologies purely to achieve external air quality objectives. An inspection of the plant room and meetings with the operator are scheduled for the second week of March 2006 in Nagoya, Japan.

Visibility or 'haze' is a recurrent problem in highly urbanised areas with polluted air from tunnels contributing to the problems in Europe and Japan.

Electrostatic precipitators ("EP's) in Japan

Electrostatic precipitators were first introduced into Japan in 1979 in the Tsuruga tunnel (2.1 kilometres).

These systems were introduced to allow comparatively cheap longitudinal ventilation in congested tunnels. Long tunnels combining longitudinal ventilation and EP's were pioneers in Japan with the Kan'etsu tunnel (11 kilometres) in 1985. This tunnel combines longitudinal ventilation using intake and exhaust shafts and EP's in bypass passages.

Japan has the largest number of EP's installed in road tunnels in the world.

In Japan of around 8,000 road tunnels, 40 have been fitted with electrostatic precipitators.

A definitive list of road tunnels with EP's was compiled for the author by the Japanese manufacturers but this table is not publicly available at their request.

EP's are generally installed to address in tunnel visibility without consideration of air quality outside tunnels. Usually this is because the installation of EP's at an intermediate point is considered more economical than a ventilation shaft to achieve the required mixing of fresh air with polluted air.

Inspection of the Tokyo Bay tunnel revealed the logic of this where a long climb from the bottom of Tokyo Bay, which would otherwise require intermediate ventilation shaft, is provided with in ceiling electrostatic precipitators to ensure tunnel visibility requirements are met. The equivalent occurs in high mountain passes and the like.

EP's and the environment

In Japan there are at least 7 tunnels which use EP's to reduce particulates to the environment for external environmental reasons.

The preferred way of incorporating filtration [in Japan] was not to install EP's in ventilation stacks, but to place them within bypass passages within tunnels.

Although technically correct this assertion is not so with respect to environment emissions. Indeed for environmental purposes EP's are always installed in the exhaust ports of Japanese tunnels. For example EP's have been installed in the base of ventilation stacks in the Tennozan (2 kilometres), Kanmon (3.5 kilometres), Asukayama (0.6 kilometres), Midoribashi (3.4 kilometres), Hanazonobashi and Hasumiya tunnels.

No technical data was forthcoming which demonstrated the actual effect of the use of these technologies on ambient air quality around the dispersal points of tunnels.

The reason universally given for the installation of these technologies was "to limit" particulate emissions in response to community concerns, but without [any access to scientific investigations which provide any insight into actual performance or even] support by technical assessment, dispersion modelling or any air quality monitoring at nearby receptors.

EP manufacturers in Japan

There are three major manufacturers of EP's in Japan being Matsushita Electric Company Limited, Mitsubishi Heavy Industries and Kawasaki Heavy Industries.

The investigations for this report included talks with executives and technical representatives of all three organisations being Matsushita Electric Company Limited, Mitsubishi Heavy Industries and Kawasaki Heavy Industries.

The inspections and numerous communications with these companies over the past years, conducted for this report included visits to the Matsushita office and factory in Nagoya, visits to the Mitsubishi headquarters in Tokyo and the companies Takasago research and development centre in Kobe, and attendances on Kawasaki Heavy Industries main office in Tokyo. All three companies are in the process of refining charged plate electrostatic precipitators similar in design to those used by Trion and CTA Technologies in Europe. Efficiencies of at least (and often more) of 80% of the removal of particles are claimed.

Information provided by these three companies that can be disclosed can be viewed in the appendices. The December appendices contain the most recent information available (as requested in November 2005):

- Matsushita Electric Company Limited - Appendix F;
- Mitsubishi Heavy Industries - Appendix G;
- Kawasaki Heavy Industries - Appendix H.

There are subtle differences in the technologies being refined by each of these companies. Importantly each of the companies is claiming that for a given air speed the efficiencies are increasing as a result of their refinements. CTA technologies from Norway have also provided advice that their technology has significantly improved performance although I have not had the opportunity to inspect the new technology and fresh technical data has not been provided.

For example at low speeds such as 9m/sec efficiencies are claimed of in the order of 90% (on a mass basis) are achieved in the laboratory while in an installed facility at the Asukayama (0.6 kilometres) speeds of up to 13m/sec it is claimed they are achieving efficiencies of around 80% (on a mass basis).

The difficulty with the claimed efficiencies of the Japanese technologies is that they are on a mass collected basis.

From a health point of view the more important criteria is the percentage of particles removed for each particulate size range. In this regard the analysis conducted by the technical university in Graz for the Austrian technology is superior as it provides data on the harvesting efficiencies for different size distribution.

In fairness to the Japanese technology data on the relative efficiency of removing particles of 2.5pm and below is an extremely difficult matter and raises substantive technological debates about what, if anything, you are measuring and what level of assurance can be had that the results are meaningful.

Nitrogen dioxide removal

Nitrogen dioxide is produced by high temperature combustion of conventionally powered internal combustion engines.

In Japan joint research among Ministry of Land, Infrastructure and Transport, Japan Highway Public Corporation, Metropolitan Expressway Public Corporation and Hanshin Expressway Public Corporation was carried out to develop reduction technologies for low concentration Nitrogen Oxides. Two types of reduction system were developed in 2004.

In one of the systems called ‘adsorption’ system, NO2 molecules are removed by the physical adsorption effects of removing agents. In the other system called ‘absorption’ system NO2 molecules are chemically changed to neutral salts by removing agents soaked in alkaline water solutions and are removed by the absorption of the neutral salts. Both systems claim they secured NO2 removal efficiency of 90%.

These technologies both require cleaning of particulates from the air prior to NO_2 removal. In other words the effectiveness of EP technologies has allowed the development of the NO_2 technologies. If it were not for the improvements in the EP air cleaning technologies it would not be possible to further refine the NO_2 cleaning equipment.

Inspections were undertaken of the different materials used for NO_2 adsorption and absorption during the course of these investigations. Importantly the author was not satisfied that it could as yet be demonstrated these technologies were robust enough for long term operation in a real tunnel due to the apparent lack of robustness in the NO_2 adsorption/absorption interface. Full scale trials will address this issue.

Metropolitan Expressway Public Corporation has decided to trial both technologies for Nitrogen removal system in the ventilation stacks of Central Circular Shinjyuka Tunnel. The tunnel is located in crowded city area where it is difficult to comply with the local environmental standards for NO_2. This will be the first full scale test of these two technologies.

It is also likely that the vehicle fleet mix within a particular tunnel may affect the longevity of these materials as a high degree of, say, diesel emissions may result in a hydrocarbon ‘deposits’ obstructing the adsorption and absorption processes on the various technologies. No doubt this will be a matter for refinement as these technologies are trialed and refined over the next few years.

4.4 Norway

Of slightly less than 1,000 tunnels in Norway approximately 7 have electrostatic precipitators. The author has inspected six of the tunnels fitted with EP's.

Most of these tunnels use EP's on an as needs basis. With the exception of the Laerdal tunnel installation of these systems has been principally driven by philosophical and political considerations in substantial part due to the activities of CTA technology and Trion. It is difficult to determine the performance of these systems for a range of reasons including:

- Electrical faults have meant many have not been in use for some time
- The use of studded tyres in Norway creates dust - and these EP systems were designed for both combustion and dust removal
- The road Authorities tests have questioned the value of such systems (Cost v. Environmental benefit.)

5. Other Technologies

5.1 Bag Filters

Bag filters have been traditionally used in mining and industrial environments to remove particulates. They are extremely reliable, well proven and a robust technology for use in a range of environments from hospitals to mining operations and foundries.

These technologies have also been used with limited success in road tunnels (eg. retrospective installation in Tenozan tunnel Japan). This type of technology is not well suited to tunnel air, and particularly that component of most interest from the environmental point of view, being the large numbers of small particles.

In the context of environmental performance for road tunnels bag filters are not currently considered as efficient or effective as alternative technologies such as the latest generation of electrostatic precipitators. This is because of the very low concentration of particles and their particle size distribution in tunnel air.

5.2 HYDER Consulting Pty Ltd

Hyder are in the process of securing international protection for a novel air cleaning technology which couples what is in substance a small gas turbine powered power station with treatment of tunnel air. In essence the gas turbine consumes pollutants – including particulates.

Issues with NO production are said to be technically resolved. Hyder forwarded a confidentiality agreement for execution prior to forwarding more particulars of the concept.

It is unlikely such a system would be chosen for a project – even if the NO generation issue was resolved as it amounts to changing a road tunnel infrastructure project into a gas turbine power station.

5.3 Indigo Technologies

Indigo Technologies (Qld) in conjunction with Adelaide University have developed an 'agglomerator' which increases the effectiveness of particle emissions.

This technology is analogous to the pre-ionisation component of all EP's used in road tunnels – but a technology which is not commonly used in coal powered power stations. It is unclear whether the agglomerator would significantly improve the efficiency of existing road EP's – or even whether its use would make the robust power station type EP's suitable for road tunnel use.

The information provided by the manufacturer is reproduced in Appendix K. The data provided suggests that at least in the coal power station environment high removal efficiencies can be achieved. Arrangements are being made to meet with the company in Brisbane and the US to further investigate this technology.

Importantly the technology is aimed at reducing the emissions of $<2.5\mu m$ particles – a size range which has traditionally been problematic for particle removal.

5.4 Clean Teq Pty Ltd

Cleanteq uses a range of non thermal plasma and biocatalytic filter technologies to treat polluted air. At the time of writing this report it was unclear what volumes of air could be 'treated' and what the outcome of such treatment would be for polluted tunnel air.

Further inquiries are being made regarding this technology. To date it has not been used in tunnels. Further information has been sought on these technologies.

Information on biocatalytic filters and the non thermal plasma technologies is available in Appendix L of this report.

6. Findings

In summary this investigation finds:

- Motor vehicle emissions adversely affect human health and the environment
- Tunnels are built to enhance the mobility of traffic, a consequence of that is the redistribution of the emissions of motor vehicles
- By far the overwhelmingly greatest benefits for air quality are achieved through national and local measures which impose performance requirements on the pollution emitted from motor vehicles.
- Unlike surface roads, tunnels provide a range of opportunities to redistribute vehicle emissions so as to improve local air quality
- In the vast majority of circumstances appropriate environmental performance of tunnels is achieved through optimized discharge point design (dispersion) and operational procedures.
- Portals and stacks of tunnels require special consideration as contaminants are emitted from limited locations compared with discharge along the full length of an equivalent surface road
- Because of the potential for unacceptable environmental effects in an area around the tunnel air discharge points it is essential that an analysis be conducted so as to ensure an appropriate design solution is implemented.
- The range of measures to manage air quality include:
    - Strategic planning
    - Careful road geometry design (slope, intersections, configuration)
    - Contaminant dispersion techniques

    - Contaminant removal technology
    - Regulation of traffic use
    - Operational aspects of the tunnel

- In most circumstances the achievement of local air quality objectives will be satisfied by robust and dynamic design of the tunnel and its ventilation strategy.

- Dispersion techniques are effective for all contaminants

- Removal technologies only effect the concentrations of specific contaminants

- There are certain cases where the use of tunnel air contaminant removal technology may be appropriate due to the specific circumstances of the tunnel and the surrounding environment.

- In most cases the best overall environmental performance is achieved using dispersion techniques

- Provision should be made for the ongoing design and maintenance of air quality monitoring equipment .

- The environmental costs of measures designed to manage air quality should form part of the assessment of different options.

- The environmental consequences of energy consumption must form part of an assessment of air management options.

- A decision to use a tunnel should be made after consideration of transport options.
- If the use of a tunnel is considered appropriate measures to ensure appropriate environmental emission performance should be adopted.

- What constitutes appropriate environmental emission performance should be determined for each project and its particular circumstances.
- Achieving an articulated external air quality objectives (the agreed environmental emission performance) should form the foundation for assessing the environmental performance of a tunnel
- Where alternative approaches to achieving the same desired environmental performance exist preference should be given to those systems which are most robust.
- Passive systems, such as slots and vents, should be afforded priority over systems requiring energy consumption, monitoring and special control.
- Relocation and more detailed design analysis to promote passive solutions should be undertaken in preference to using technologies which demand ongoing maintenance, energy and monitoring to achieve comparable environmental performance.
- Electrostatic precipitator technology has now advanced to a level where it may, in some circumstances, assist achieving an articulated external air quality objective by effectively remove a significant proportion of particulates from emissions in congested urban tunnels.
- The Japanese electrostatic precipitators have been installed in at least 7 tunnels principally for external environmental air quality reasons.
- The Austrian technology is currently being installed in an Italian tunnel principally to address external air quality issues.
- The reason for the installation of air cleaning technologies in a number of road tunnels in Norway and Japan has been principally external air quality issues driven by political considerations.
- No data is available to date anywhere in the world which demonstrates the actual effect on external air quality with respect to the use of electrostatic precipitators for external air quality purposes.
- Most electrostatic precipitators are installed to improve in tunnel visibility in long tunnels where visibility limits are reached well before the carbon monoxide limits.

- The use of electrostatic precipitators improves visibility in long tunnels through particulate extraction and thereby avoids the need for intermediate air shafts.
- Ventilation stacks are routinely used in road tunnels in urban environments where external air quality is an issue in Norway, Japan, Germany, Austria and Australia.
- The development of NO air cleaning technologies in Japan is progressing well with competing (and different) technologies being explored.
- The effectiveness of NO air cleaning technologies is currently dependent upon the efficiency of the removal of particulates prior to the NO removal process.
- The long-term use of NO air cleaning technologies has not been demonstrated for congested road Tunnels. Trials to test these techniques are scheduled to commence shortly in Japan

7. Appendices

Appendices are located on the enclosed CD accompanying this report.

Appendix A
Aigner – ECCO Air Cleaning Technologies

Appendix B
Indigo Technologies

Appendix C
Clean Teq Pty Ltd

Appendix D
Independent analysis results of Aigner technology

Appendix E
Copy of Aigner letter for Rome project

Appendix F
Matsushita Electric Company Limited

Appendix G
Mitsubishi Heavy Industries

Appendix H
Kawasaki Heavy Industries

Appendix I
'*An international perspective on current pollution dispersion methodologies'*, February 2000 – paper by the Arnold Dix

Appendix J
The report and associated material from the public inquiry in June 2000 – "*International Workshop into Tunnel Ventilation",* conducted in Sydney