STATE OF WORLD PRACTICE
URBAN MOTORWAY TUNNEL AIR TREATMENT SYSTEMS
2024 REPORT

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1. Executive Summary

The Advisory Committee on Tunnel Air Quality have commissioned the author, to conduct a field and fact based review of the current state of international practice of installed tunnel air treatment systems in urban road tunnels with a focus on 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.

1.1. Health

For many years it has been known that exposure to particulates from internal combustion engines causes human ill health with a special focus on diesel particulates which are generally accepted to be carcinogenic, as reflected by the designation of the International Agency for Research on Cancer (IARC) as carcinogens.

1.2. Government Controls for Vehicle Emissions

Governments internationally have responded to these adverse health impacts by imposing increasingly strict regulatory controls on vehicle emissions and encouraging the uptake of alternative energy vehicles.

Vehicle manufacturers have universally substantially decreased the emissions from internal combustion engines powered by fossil fuels.

Vehicle emission controls have substantially reduced harmful vehicle emissions from internal combustion engines and the proportion of non internal combustion powered vehicles is increasing in motor vehicle fleets throughout the world, including Australia.

In addition to particulate emissions from engines, there are particulates from tyres, brakes, and even the road surface which are created by moving vehicles. These pollutants are gaining increased interest from the public and health professionals.

1.3. Industrial Air Cleaning Industry

The industrial air cleaning industry, which is responsible for large volume air cleaning and more recently the domestic air cleaning industry, has responded to these concerns by developing – and continuing to develop - high volume air cleaning technologies. Reputable companies produce and warranty the performance of high volume air cleaning technologies.

1.4. Tunnels

Transport tunnels confine vehicle emissions and particulates generated, interfere with the normal process of emission dispersion and restrict the conversion of NO_x to NO_2. The focus for New South Wales transport has been on road tunnels but increasingly there is international interest in understanding mobilised particles in rail tunnels too – especially metals and mobilised dust from train brakes.

Natural atmospheric processes occur when motor vehicles are operating on the surface or on elevated nonconfined roadway structures that disperse vehicle emissions including particulates.

Rightly, attention has been drawn to the implications on human health of the confinement of vehicle emissions in tunnels. Conversely there has been little attention to document the benefits of separating people from vehicle emissions by containing them in tunnels. The issues created by surface road use near people is likely to gain more attention in the future.

1.5. Explored Installations for this Study

This report draws upon evidence collected by the author 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.

This report is based upon inspections of actual equipment, interviews with key stakeholders from the air cleaning industry, manufacturers and road authorities.

Confidential field attendances, site inspections and interviews on projects and their technical advisors, coupled with telephone and internet attendances on key personnel in other countries were conducted and this report is prepared based on this direct and factual material. This is not a literature review.

1.6. Conclusions from Field Investigations

As a result of this direct information, it is concluded that:

a. Tunnel air cleaning technology for the removal of particulates is installed and:
    i. operational in the Shinjuku tunnels in Tokyo
    ii. may have been operated in Wan Chai tunnels in Hong Kong but is not now
    iii. is being installed – not yet operational – in two tunnel projects in Hong Kong (Central Kowloon Tunnel, and Trunk Road & Chakwo Lin Tunnel)
    iv. has been barely used and not maintained since installation completion in 2007 on the Calle M30 in Spain
    v. it is maintained but not routinely activated in Beijing
    vi. it is not used in Italy
    vii. it is not routinely used in Norway for external air quality management
b. NO_2 removal technology is installed and:
    i. operational in the Shinjuku tunnels in Tokyo
    ii. was operational but is no longer operational in Wan Chai tunnel in Hong Kong
    iii. has been rarely used over the last 17 years in Spain
    iv. maintained but not routinely used in the tunnel in Beijing
c. NO_x removal technology is installed and:
    i. operational in the Shinjuku tunnels in Tokyo
    ii. was operational but is no longer operational in Wan Chai tunnel in Hong Kong
    iii. has been rarely used over the last 17 years in Spain
    iv. maintained but not routinely used in the tunnel in Beijing
d. Dispersion stacks:
    i. are constructed and used to disperse tunnel emissions in the Shinjuku tunnels of Japan

ii. short dispersion stacks are installed in the Wan Chai tunnel in Hong Kong
iii. are not installed in Madrid, Spain on the Calle M30 project
iv. are generally routinely installed on new tunnels but are often only used in exceptional circumstances due to the improvements in tunnel air quality

1.7. Regional Summary

1.7.1. China

In Hong Kong the main driver for the use of air cleaning technology has been the removal of the vertical ventilation structures from the skyline as they are perceived to be an unwelcome obstruction of the extremely valuable Hong Kong Island real estate view to the harbour.

China continues to embrace its aggressive 'blue skies' policy which includes forcibly shutting industry during periods of poor weather (typically autumn and winter for extensive periods of time) imposing increasingly strict emission controls, prohibiting the use of aged vehicles, accelerating the use of alternative fuel vehicles and active tree planting programs.

1.7.2. Japan

The Shinjuku tunnels in Tokyo use two competing technologies supplied by two different Vendors, both of which convert NO_x to NO_2 for subsequent NO_2 removal by the tunnel air cleaning plant and thereby substantially reduce the discharge of NO_2 to the environment. These technologies remain in operation and are both considered effective.

1.7.3. Spain

In Spain the M30 Project has been severely criticised for its wasteful use of public resources and the air cleaning technologies are part of that criticism. Mostly the systems are not used with many installations being closed for spare parts for the few installations that are used during a very small proportion of the day. In Spain – in substance – the government has returned to a full portal emission regime denying residents near the tunnels both the benefits of elevated stack emissions and active pollution removal.

However, Spain is now considering some new urban road tunnels and is again considering air cleaning technologies as part of the urban solution. The air cleaning technologies installed 17 years ago may be reinstated and bought into a functional state as part of the regulatory and political approvals process for the new road tunnels.

1.8. Discussion

In each instance, the use of the technology for air cleaning has not been driven by innovations in air cleaning or even the acute need for cleaner air. In the case of China, the key driver revealed during my investigation was gaining approval and public acceptance of the project in the absence of vertical ventilation structures in order to protect urban amenity.

In the case of Shinjuku, installing the air cleaning technologies were in response to local political pressures from residents opposed to the Shinjuku tunnels while in Spain the use of the technologies was as much a part of 'state of the art branding' for the project as

justification for the removal of ventilation stacks which were needed on technical grounds. In Spain there is great community opposition to vertical ventilation towers.

Whilst it can be concluded that there is considerable experience for particulate removal systems (electrostatic precipitator and mechanical) the installation of gas cleaning techniques to convert NO_x to NO_2 is only used in a very small number of tunnels. The author has only inspected such technologies in Japan in the Shinjuku Tunnel. Activated carbon systems have been observed and inspected in several countries including China during the August and September 2024 inspections. All technologies work at removing NO_2 at various efficiencies.

In Japan the local road administration expressed serious concerns about the energy consumption of the system denitrification and the polluted waste streams that it produced. The technological burden of the denitrification plants was described as "significant" because in the case of both de-NO_x technologies special expertise is required to renew and maintain the equipment and to harvest the intercepted oxides of nitrogen. In each case substantial "offsite" de-NO_x infrastructure and expertise is required to operate and maintain the equipment.

1.9. Particulate and Gas Removal Technologies – Efficiencies and Costs

This fact finding mission concludes that both particulate and gas removal technologies can be installed to treat large volumes of tunnel air.

The efficiency rate for the removal of PM_{10}, $PM_{2.5}$, and $PM_{1.0}$ is consistently greater than 90% but under heavy volumes can fall to 80%. The capital cost alone of the equipment to remove the particles is between AUD $30,000 and AUD $50,000 per m^3/s.

The removal of NO_x is consistently greater than 80% at a capital cost alone of between AUD $15,000 and AUD $25,000 per m^3/s.

In combination the capital cost for particle and NO_x removal is between $45,000 and $75,000 per m^3/s. This means that for a hypothetical 1000 m3.sec combined air cleaning station, the capital cost should be between 45 and 75 million dollars.

This means that with the technology operating at expected efficiency, one tenth of the particles and one fifth of the gases will still be discharged into the environment.

No figures were made available for the energy cost of running the systems, although pressure drops in the order of 300Pa for the particle filters and 450Pa were reported for the NO_x removal.

What this means is that the energy consumption of each ventilation station will be increased significantly in order to blow means air through the air cleaning equipment. The amount of extra energy required will be in the order of the equivalent of hundreds of households.

This means that the impact of the extra energy required to operate the air cleaning equipment should be considered in terms of its impact on the grid and achieving the State's renewable energy targets. The impact is substantial but determining if the benefits outweigh the burden is beyond the scope of this report.

No figures were made available of the maintenance costs. No figures were made available for the disposal of accumulated wastes costs.

In summary, the costs are summarised in the following table:

	PM_{10} – $PM_{1.0}$	NO_x
Efficiency (Under heavy volumes)	>90% >80%	>80%
Pressure drop	Approx. 300 Pa	Approx 450Pa
Capital Cost per m^3 treated	$30k-$50k	$15k-$25k

Environmental costs which are beyond the scope of this report include:

- Increased demand for non renewable energy (baseload)
- Substantial investment in stainless steel and other metals to build the equipment
- Creation of concentrated waste streams
- Contamination of water
- Complication of response in the case of fire

1.10. Cost Benefit

There is a universal lack of '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 large economic and environmental costs of the technology. This is especially pronounced in countries sensitive to triple bottom line accounting such as Scandinavia and places that burn fossil fuels for electricity such as the United States. No actual cost benefit studies are in the public domain.

In all countries investigated where the installed tunnel air cleaning technology is actually operated, concerns were expressed by the operators about the cost and measured benefit of the maintenance, energy consumption and waste generation of the technologies. The Vendors of equipment are especially sensitive to these issues and consistently expressed concern that their equipment must be maintained by suitably competent personnel (especially the high voltage equipment) and that there must be sufficient budget to maintain the equipment. The experience in Spain was especially problematic as the equipment had fallen into disrepair and is currently in the process of being recommissioned. In Hong Kong there was also an example of an installation falling into disrepair and recommissioning being problematic.

1.11. Operational Costs

The gathering of actual operational costs including energy, waste disposal, labour, maintenance and spare parts for technologies from the various manufacturers investigated, was not provided by any of the contacts. All facilities, all subcontractors, all maintenance contractors and all government departments **declined** to share such information.

In all examined instances of air cleaning technology, its installation was required to achieve political objectives – typically approval to build a road. In no instance was air cleaning required to achieve set environmental performance criteria.

In no jurisdiction was the inherent relationship between particles and ill health considered in the context of the residual or background particle load. Even if there are no internal combustion engines, tyres and brakes will produce particles. Should there be no vehicles at all, background natural particles such as salt from the sea will also pose a health issue for humans.

Ultimately the use of these air cleaning technologies is a question of value.

From my involvement with tunnel air pollution, motor vehicle emissions and human health over the last three decades I am in no doubt that in Australian cities the use of air cleaning technologies does not represent good value for money for the health benefits it may bring. The capital and operational expenses for air cleaning technology in Australian cities cannot be justified on the basis of the theoretical and at best marginal, health benefits they bring.

1.12. The Use or Not of the Air Cleaning Equipment

In several countries investigated installed equipment was not used. In one country it appeared installed equipment was used for a short time and then neither maintained nor used. In more than one instance where the technology was used it appeared no effort had been made to dispose of the collected waste. This suggests that in some circumstances the decision to install and operated tunnel air cleaning technologies is made to achieve a political objective.

In Japan the air cleaning technology has been diligently used, its efficiency continually reported and the systems maintained. The challenge now is that there are no agreed criteria to turn the systems off. Japan has experienced enormous improvements to its air quality but in the absence of an agreed air quality threshold there appears no practical mechanism to determine when the cost exceeds the benefit of operating the technology.

Combining all of these observations it is clear that in the absence of an agreed criteria to determine the value proposition of the tunnel air cleaning its adoption is most often politically based and if operated there is no agreed criteria to determine when it is no longer necessary due to air quality improvements.

In countries which in the past had extremely bad air quality, such as parts of Japan and China, air cleaning technologies was justified as part of an 'all measures' action to help address severe air quality issues in what could be considered a state of air quality emergency.

1.13. The Science of Tunnel Air Dispersion

The science of tunnel air dispersion is well advanced. Appropriately designed and operated tunnels utilising elevated ventilation structures, mimic or often exceed the dispersion characteristics of surface roads and elevated non-enclosed roadways.

There are no examples of failed vertical dispersion systems – there is no known evidence of unacceptable air quality caused by these structures in areas where such dispersion structures are used.

There is only one example known to the author of a potential measurable impact of emitted tunnel air from an operating ventilation tower.

The reported finding is a desktop review of limited available monitoring data and the anomaly that is detected is curiously from a site most distant from the stack compared with the other three data sets and only on one day.

Given the attention that has been made of road tunnel air emissions and their impacts it is noteworthy that no other studies have ever suggested an impact – and the impact in the Hibberd analysis is very small.[1]

These findings suggest that the design and use of appropriately operated air dispersion stacks is directly related to minimal impacts to air quality at ground level. Put another way it suggests that the ventilation stacks work as intended.

The dispersion mechanisms are well known and work.

There is thought that the containment of internal combustion engine emissions in road tunnels provides an opportunity to remove particulates and oxides of nitrogen. This argument can also apply to congested areas within cities as reflected in Japan's use of curb side NO_x removal technologies at especially busy intersections.

A range of technologies exist which can reliably remove a significant proportion of the particulates, NO_2 and in some instances even a proportion of the NO_x. This means that air quality coming out of tunnel ventilation stacks can be better than the ambient air quality that enters the tunnel.

1.14. Summary

This field based investigation of the use of air cleaning technologies in urban environments around the world indicates:

1. Internal combustion engine combustion emissions controls are a highly effective means of managing particulate and NO_2/NO_x emissions
2. Emission controls on vehicles are the best way to manage air quality concerns
3. Air cleaning equipment is mostly installed in tunnels to secure regulatory approvals and political support for projects
4. NO_x removal technologies are complicated to install, maintain and operate – with Japan being the only known country to regularly utilise installed systems

1 *https://www.chiefscientist.nsw.gov.au/__data/assets/pdf_file/0008/272168/SydneyTunnelAmbientDataAnalysis_Hibberd_FinalJune2019.pdf*

2. Introduction

Tunnels provide unique opportunities to create new efficient linkages for travel within developed urban environments. These new links optimise the environmental efficiency of vehicles by enhancing the efficiency of motor vehicle journeys and generally result in reduced emissions for the equivalent number of journeys were there are no tunnels.

The responsible managements of captured internal combustion engine emissions include consideration of utilising tunnel air cleaning technologies. Indeed, the use of tunnel air cleaning technologies is just one of the options for managing internal combustion engine emissions including at source (including filtration and other onboard solutions), changed energy source (e.g. electric) and taking advantage of the opportunity of captured internal combustion engine emissions within the encapsulated tunnel environment.

Health and environmental regulators at state, national and international levels, entrench strict environmental performance requirements by imposing strict conditions on both tunnel design and operations. These controls impose environmental performance requirements that are not possible with open roads which emit pollutants at the level of vehicle exhaust pipes and often in close proximity to people. Development around such tunnel portals and tunnel ventilation facilities is likewise usually carefully monitored and managed.

The trend of increasingly stringent vehicles emissions control in Australia continues with Euro 6 emission standards to be introduced over a 12-month period commencing late 2024. This means the trend in urban air quality is expected to continue both around the normal road network and in tunnels.

Australia continues its renaissance in underground transportation infrastructure construction and operation. Over the last 30 years each of Victoria, New South Wales, Queensland and Western Australia have sought to define best practice in underground road vehicle tunnels resulting in a range of approaches to the common challenges associated with approvals to construct and operation of tunnels.

During the same period of time there have been substantial changes to international practices especially with respect to tunnel safety. Catastrophic fires in the latter part of the 20th century in Europe resulted in formulation of minimum best practice for Trans- European Road tunnels (EU Directive 2004/54/EC) while in the United States there have been several revisions of NFPA 502 (the American tunnel safety standard).

To complicate the global situation further there has been the emergence of new tunnelling *'super powers'* with China's aggressive tunnel construction program eclipsing the entire construction program for the rest of the World.

The financial landscape for tunnel infrastructure has also changed. The more onerous international 'minimum requirements' has sent governments and consultants scrambling back to their designs with an eye for better value during construction and minimised operational costs.

Greater awareness of the long-term environmental consequences of underground road infrastructure projects has also prompted a critical review of strategies to minimise energy consumption and maximise road tunnel performance.

Improvements to vehicle emissions have for the most part accelerated, reducing the environmental impact of vehicle pollution per vehicle however this in turn has been balanced by substantial increases in the number of vehicles and the plateau of improved environmental performance especially with respect to the oxides of nitrogen especially for diesel engines.

This report provides the author's perspective on current international practices in the use of air cleaning technologies in urban road tunnels in the face of these trends.

The opinions contained within this report are as a result of extensive discussions and ongoing field investigations in numerous countries.

3. General Discussion

Early urban tunnels such as those built in the 1960s and 1970s tended to use transverse ventilation to maintain in tunnel air quality. Ventilation stacks were sometimes used to augment portal emissions dispersing.

The basic principle of tunnel ventilation is the dilution of vehicle emissions by providing fresh air and then removing the exhaust air from the tunnel. The exhaust air can be removed via a portal (a location where the tunnel carriageway opens up to the surrounding environment), via a ventilation outlet (such as a stack), or via a combination of both. Ventilation systems are traditionally characterised by the way the air flow in the tunnel is produced and in which direction the air is blown – in relation to the axis of the tunnel. Longitudinal ventilation, in its simplest form, comprises fresh air introduced within the entry portal and exhaust air expelled out of the exit portal.

Transverse ventilation works on the same principle of dilution and removal as longitudinal ventilation; however, the supply of fresh air and the removal of exhaust air occurs across the tunnel (i.e. transversely). The approach to tunnel ventilation has changed dramatically over time, mainly due to the significant reduction in vehicle emissions from emission control technology and better fuel quality. Improved vehicle emission technology and the construction of twin tube tunnels operated with unidirectional traffic now facilitates the use of longitudinal ventilation systems for long and heavily trafficked tunnels. All road tunnels built in Australia over the last 25 years have been designed with longitudinal ventilation systems.[2]

Up until the introduction and uptake of more stringent motor vehicle emission standards in the 1980s tunnel emissions were often associated with the deposition of combustion residues on surrounding properties and vegetation and in extreme cases were associated with damage to fruit crops in countries such as Japan.

All vehicle engine manufacturers of vehicles used in Australia have had imposed stringent motor vehicle emission reduction programs over the last 40 years. Over the last decade China has imposed strict 'blue sky' policies which has in part driven substantial improvements to the voluminous Chinese motor vehicle industry including its ascent as the world's highest volume electric vehicle manufacturer.

At the same time the length of tunnels (individually and collectively) in urban environments has greatly increased and there has been an almost universal move to longitudinally ventilated tunnels as emissions from the world's vehicle fleet substantially improved.

Long longitudinally ventilated tunnels carrying large numbers of vehicles have the potential to capture significant volumes of internal combustion engine emission loads within tunnels.

The vast majority of tunnels around the world discharge these captured emissions via the tunnel portals. The untreated discharge of these emissions is now mostly considered reasonable as the substantial reduction in pollutants from modern internal combustion

[2] https://chiefscientist.nsw.gov.au/__data/assets/pdf_file/0007/289240/TP04_Road-Tunnel-Ventilation-Systems.pdf

engine vehicles coupled with both in tunnel dilution and dilution and dispersion outside the tunnel result in acceptable air quality goals being achieved.

In some circumstances dispersion shafts are used to augment the portal emission performance and in extremely rare cases, active air cleaning technology is employed to remove some contaminants prior to discharge and in even rarer instances bypass air cleaning systems are deployed within the tunnel.

In 2015 the United States Department of Health and Human Services National Toxicology Program declared that diesel particulate exposures were related to cancer.

In 2019 the European Union, by way of Directive 2019/130, amended Directive 2004/37/EC on the protection of workers from the risks related to exposure to carcinogens or mutagens at work noting at Clause 16:

'There is sufficient evidence of the carcinogenicity of diesel engine exhaust emissions arising from the combustion of diesel fuel in compression ignition engines**.'**

In 2021 the Environmental Protection Agency of the United States specifically recognised the relationship between diesel particulates and ill health - diesel emissions cause cancer.[3] [4]

[3] https://www.cancer.org/cancer/risk-prevention/chemicals/diesel-exhaust-and-cancer

[4] Benbrahim-Tallaa, L., R. A. Baan, Y. Grosse, B. Lauby-Secretan, F. El Ghissassi, V. Bouvard, N. Guha, D. Loomis & K. Straif (2012) Carcinogenicity of diesel-engine and gasoline-engine exhausts and some nitroarenes. *Lancet Oncol,* 13**,** 663-4.

4. The Study

During 2024 contact was made with key stakeholders in tunnel air cleaning utilising the following branded technologies:

a. Filtrontec
b. Air-Quality (formerly CTA)
c. Aigner
d. Matsushita / Panasonic
e. Kawasaki
f. Fuji

Manufacturers of each of the above brands air cleaning equipment were contacted for their input into this study.

In addition, representatives of road administrations and their advisors and subcontractors in France, Germany, Vietnam, Japan, China, Hong Kong, Spain, Norway, America, United Kingdom, South Korea, Austria, and Italy, were all contacted, and inquiries made about the installation and use of air cleaning technologies in their road tunnels.

There are political sensitivities about information contained within this report. For example the fact that it is only in Japan that air cleaning technologies are turned on and operated on a daily basis and that in all other countries the systems are not routinely switched on and often not maintained.

The author would like to think that the reason the equipment is usually not turned on and used is because of the substantial improvement to air quality since the requirements for air cleaning technology were made.

5. Findings

5.1. Overview

In countries with existing air cleaning technologies which are designed and used for external air quality management in an urban context such as Spain, Italy and Norway, Hong Kong and China the technology is either not used, or is used occasionally or for very short periods of time (minutes or perhaps one or two hours only). The consistent theme is that the technology was needed for an approvals process and that the 'official' reason for no longer using, using sparingly or decommissioning is that air quality is now better than expected within the tunnels.

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.

Mainland Chinese companies have acquired former European air cleaning technology companies such as CTA and expanded their portfolio of air cleaning technologies.

5.2. Cost to Purchase, Maintain and Operate

It is difficult to obtain data on the actual costs to purchase, install, operate, and maintain tunnel air cleaning technologies.

The actual cost of installing these technologies includes the engineering design aspects of having air cleaning technology integrated with an emergency ventilation system as well as the extra civil works and control systems to integrate the technologies safely into the tunnel systems.

There was consistent concern expressed about finding suitable persons qualified to maintain and repair the high voltage electrostatic precipitator systems. This may partly explain why installed systems in Norway, Spain, South Korea, and Hong Kong, have fallen into disrepair.

There is also no available data on the cost of managing harvested pollutants.

None of the above matters are a prohibition to installing the technology – but they are matters to be considered as part of any cost benefit analysis.

The best information made available during the course of this investigation on the cost of tunnel air cleaning systems is summarised in the following table:

	PM_{10} – $PM_{1.0}$	NO_x
Efficiency (Under heavy volumes)	>90% >80%	>80%
Pressure drop	Approx. 300 Pa	Approx 450Pa
Capital Cost per m^3 treated	$30k-$50k	$15k-$25k

This data has been made available to me by three manufacturers of air cleaning technologies, separately and blindly to each other, on the basis that their identities remain confidential. All are willing to quote on new projects and supply costings for specific proposed projects. This is the only public data of which I am aware of on the costs of the air cleaning technology. As noted above the technology works and is getting better and more efficient. Determining whether the technology should be used in a particular project is a matter personal to each project.

5.3. Fact Finding

5.3.1. Japan

The author continues a watching brief on Japanese air cleaning technologies. The author first inspected the Shinjuku (Yamate) tunnels in 2008 and conducted technical visits with the scientists and engineers developing what was then new technology for oxidation of NO_x to NO_2 from Matsushita, Fuji Electrics, Kawasaki Heavy Industries, and Mitsubishi Heavy Industries.

In 2008, the author also attended upon Metropolitan Expressway Corporation ("MEC") to discuss their plans for the installation and use of air cleaning technologies in new road tunnel projects.

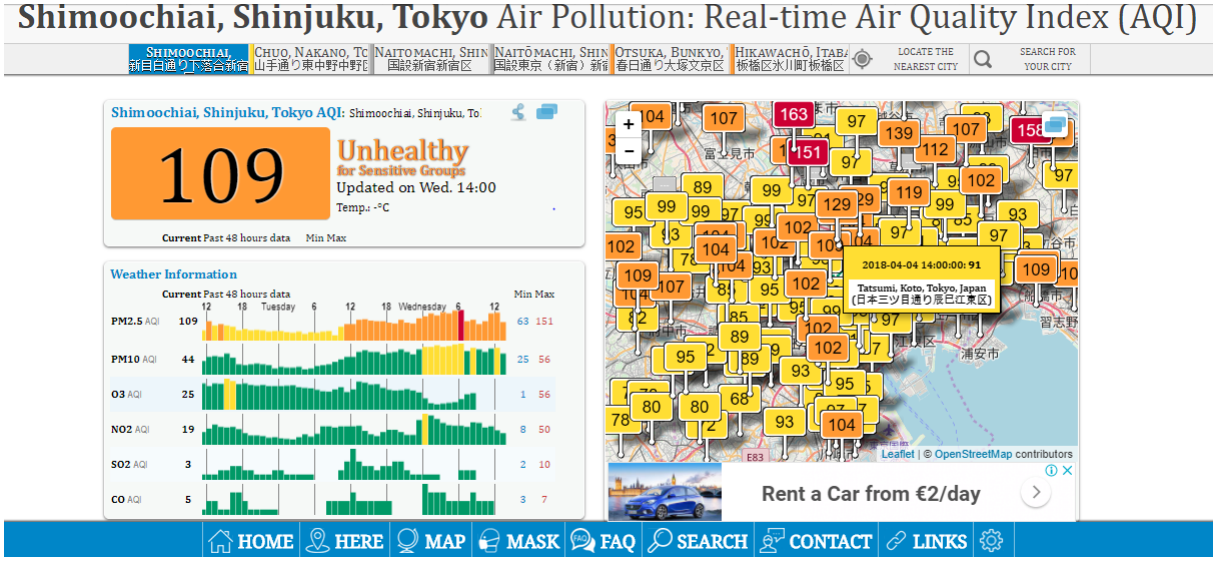
In January 2018, the author again attended Shinjuku tunnel and arranged formal meetings with technical team responsible for the Shinjuku tunnels air cleaning technologies from the MEC. Representatives from the policy, energy, environment, pollution, maintenance and public relations departments attended the meetings along with a technical translator.

This dialogue was continued in 2024 which established the current factual situation in Japan.

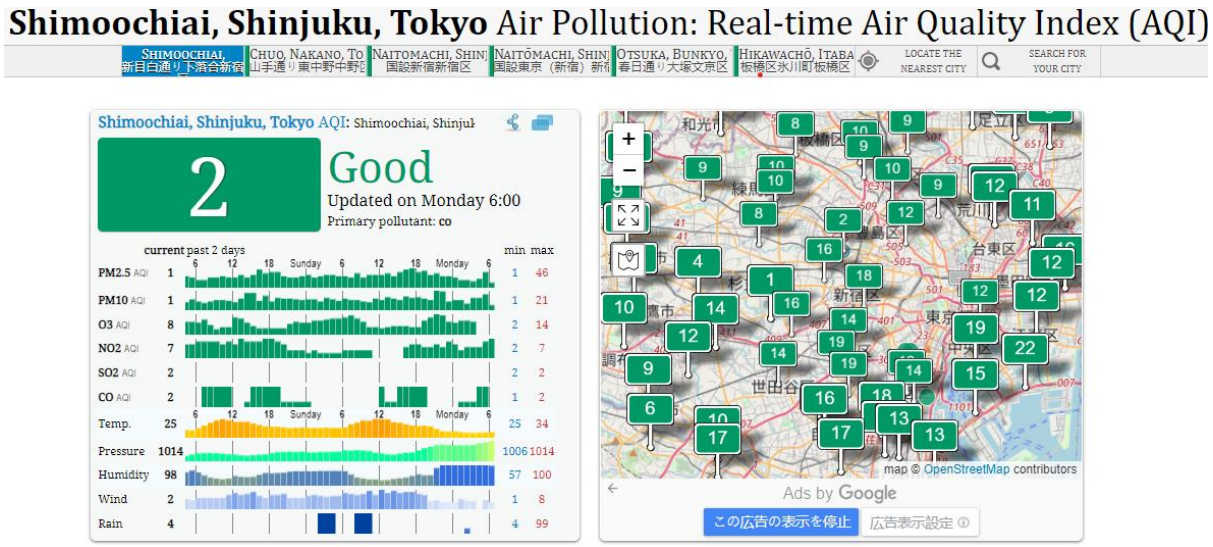
5.3.1.1. Findings from Japan

- The Ministry of the Environment of the Government of Japan have strict environmental quality standards.[5]
- Japan's air quality has dramatically improved over the last decade.
- The government authorities transparently report regularly updated air quality on their website.[6] Some of the monitoring stations are installed beside major roads or intersections to determine the influence of automobile emissions. Areas of extreme pollution can be viewed within hours via the website.[7]
- Japan has the highest number of installations of ESP and NO_2 air cleaning technologies in road tunnels in the world. By 2009 installations of ESP (not NO_2 or NO_x) technology was reportedly 52 tunnels[8], it is higher today.

[5] https://www.env.go.jp/en/air/aq/aq.html - accessed at 16:42 on 04.04.2018
[6] http://www.kankyo.metro.tokyo.jp/en/automobile/monitoring.html
[7] http://www.taiki.kankyo.metro.tokyo.jp/cgi-bin/bunpu1/p101.cgi
[8] Brandt. R., Riess. I., 2009 "Possibilities and limitations of tunnel-air filtration and portal-flow extractions" BHR Group ISAAVVT 2009 New Brunswick



Illustrates the air quality at 16:42 on 4 April 2018[9]



Illustrate air quality at 8:16am on 16 September 2024[10]

- Japan views air quality very seriously. Principally the air quality of the general airshed is regulated by stringent controls on emissions from industry and motor vehicles with internal combustion engines. The use of particle removal technologies in Japanese tunnels is, compared to other countries, common. Principally these installations are made in order to protect the air quality outside tunnel portals, especially where the roads are used principally by heavy goods vehicles and other diesel powered vehicles. This is analogous to the installation of air cleaning technologies in Monte Blanc in France and also the Chinbu Tunnel in South Korea where high truck numbers drive local community discontent. There is a strong

[9] http://aqicn.org/city/japan/shinjukuku/shinmejirodorishimoochiai/ accessed 4:42 pm on 04.04.2018

[10] https://aqicn.org/city/japan/shinjukuku/shinmejirodorishimoochiai/ accessed 8.16 am on 16.09.2024

correlation between the installation of particle removal technologies and roads with high concentrations of freight and other heavy vehicles in Japan. The initial impetus for the installation of these technologies in Japan was dissatisfaction by local residents in highly concentrated urban developments proximate to the tunnel portals and other emission points. Damage to fruit and laundry from diesel vehicle emission was common.

- The tunnel air cleaning systems installed in Japan continue to be maintained, operated, and real time data reported on emitted tunnel air quality.

5.3.2. Vietnam

I attended Ho Chin Min City, Vietnam in January 2018. Panasonic/Matsushita in Japan had from time to time referenced an air cleaning technology project in Vietnam. It is reported that the Haivan Pass Tunnel in Da Nang Vietnam is fitted with air cleaning technologies. There were conflicting reports about it containing NO_2 removal technology which would have made it of interest given it is a remote non urban tunnel.[11]

Although not an urban tunnel it is more recent than the air cleaning technology in the M30 project in Spain and has been the subject of public comment by Panasonic from time to time in terms of the innovation in the technology.

I attended Da Nang in October 2013 with the intention of attending the tunnel but was not able to access the chambers where the purported technologies were installed. Likewise, in 2018 when I made my inquiries, I was assured the technology was installed.

I was advised that I may be able to inspect the facility if I was able to get a Visa to enter Vietnam and attend.

In January 2018 I successfully gained a Visa and went to Vietnam however my contacts subsequently advised they were unable to secure a visit to the tunnel. I was again unable to secure a tunnel inspection in Vietnam in August 2024.

[11] 13th International Symposium on Aerodynamics and Ventilation of Vehicle Tunnels, New Brunswick New Jersey, USA: 13-15May 2009, ISBN 978 1 85598 1072

Vietnam air quality remains poor. (Photograph taken January 2018 Ho Chin Min City)

Vietnam is undergoing an extreme transformation and its aspirations for clean air parallel those in China. It is likely that in parallel with its industrialisation a program of aggressive clean air protection will occur. It is conceivable that such a program will include the use of air cleaning technologies in its cities. However, at this stage, I have been unable to confirm that such technologies have actually been installed or are operating in any rural or urban tunnel in Vietnam. As at the date of this report Ho Chin Min City in Vietnam is still regarded as one of the most polluted cities in the World.

5.3.3.Hong Kong - Wan Chai Bypass

Hong Kong Island experiences extreme traffic congestion. A road tunnel to relieve road congestion along the foreshore was proposed more than 30 years ago.

The government were faced with severe issues in getting approval for this particular tunnel as it runs along the reclaimed, foreshore, area at the front of the coastline of the island of Hong Kong. There were severe concerns raised by the community about this tunnel. The tunnel is 3.4 kilometres long.

Initially the environmental agency wanted particles removed from the tunnel air but subsequently they changed their requirements to include NO_2 removal. In 2013 an Environmental Permit to Operate was approved:

> *'An Air Purification System (APS), including an electrostatic precipitator system (ESP), with removal efficiency of at least 80% of dust to reduce the level of respirable suspended particulates (RSPs), and a NO_2 removal system (De- NO_2 Filter) with removal efficiency of at least 80% for NO_2, shall be adopted to improve the air quality before discharging to the atmosphere via the WVB* [West Ventilation Building], *MVB* [Middle Ventilation Building], *and EVB* [East Ventilation Building] *and its vent shaft.'*

The Air Purification System is a two stage process: a. Stage 1 – Electrostatic Precipitator to remove respirable suspended particles, and b. Stage 2 – De-Nitrification (De-NO_2) Filter to remove NO_2.

Technically it is recognised by the designers and consultants that the air cleaning technologies are of limited value, but the approvals politics required no stacks and air cleaning.

The politicians promoted the project on the basis of more than 80% reduction in NO_2. An 80% removal of NO_2 is misleading because the actual issue is NO_x because NO_x converts to NO_2 in the presence of an oxidising agents such as ozone or UV light.

By using the air cleaning technology, they have been able to justify the reduction in the height of the stacks, much lower than the air quality technical team wanted, to appease the developers and other interests that have buildings set back from the tunnel overlooking Hong Kong harbour.

The Hong Kong government rejected the two types of Japanese NO_x removal technology on the basis that it required intervention either on site or at a special factory. MEC expressed the same concern at our meetings. The NO_x technology is complex in terms of waste streams and maintenance.

The Filtrontec technology similar to that used in the M5 East trial was installed in Hong Kong. There is no creation of any waste stream for disposal in landfill using the modified Filtrontec arrangement. During the inspections in 2018 no waste stream collection was observed.

Despite my attendance in Hong Kong in August 2024, and the attendance of the CEO of Filtrontec, our requests for an inspection of the facility and control centre were denied.

Inspections of the outside of the tunnels confirmed the ventilation systems were still operational however there is serious doubt that the air cleaning technologies within the tunnels is still operable due to maintenance issues disclosed to the author by Filtrontec and CTA Air Quality at our recent meetings in Hong Kong.

It is likely the Filtrontec equipment is no longer functional – in part due to the ingress of salty water into the rooms housing the air cleaning technologies.

Photograph of the author with Elke Deux, the CEO of Filtrontec who flew especially into Hong Kong to meet with me and attend the tunnel installation. Ms Deux was also denied access to the installation.

Large installations of electrostatic precipitators with automatic washing were observed.

These have each been built to deal with 650m³/s tunnel air. (Photograph from 2018 inspection by the author.)

Processing of 650m³/s requires very large plant. (Photograph from 2018 inspection by the author.)

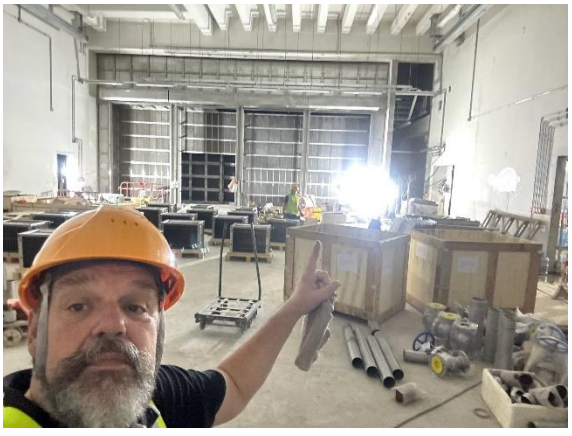
Filtrontec substantially modified the design of their activated carbon system in order to meet the Hong Kong government's strict activated carbon servicing timelines. Filtrontec claimed to be able to completely change the used activated carbon from their massive NO_2 removal facilities in a matter of minutes. These modifications are designed to ensure that even when the active carbon is saturated the system can be replenished in a very short period of time. (These photographs are from 2018 inspection by the author.)

Clean air in Hong Kong September 2024.

The air quality in Hong Kong continues to improve. This is directly attributable to a reduction in Hong Kong manufacturing reforms in mainland China under the 'Blue Sky' policy, and a remarkable modernisation of the vehicle fleet. By way of illustration Hong Kong cars were observed to consist of a high proportion of Tesla, BMW, Lexus and Toyota electric and hybrid vehicles.

5.3.4. Central Kowloon Tunnel, Hong Kong

I attended the Central Kowloon Tunnel project in September 2024 and inspected several of the six air cleaning stations being installed by Air-Quality (formerly CTA). I observed high quality stainless equipment being installed to a high standard. It is understood that these will be completed in 2025.



Conducting inspections of pre-installed electrostatic precipitators, confirming they are of high quality and made of stainless steel as required under the Hong Kong regulations.

Head of the tunnelling division of Air-Quality (formerly CTA) Johan Anderl with the author during inspections at Kowloon Central Tunnel of the waste purification plant for removing mobilised particles during the wash cycle.

Inspecting the electrostatic precipitators installation in Kowloon Central Tunnel with Johan Anderl.

5.3.5. T2 Trunk Road and Chakwo Ling Tunnel, Hong Kong

I inspected the T2 Trunk Road and Chakwo Ling Tunnel installations in September 2024.

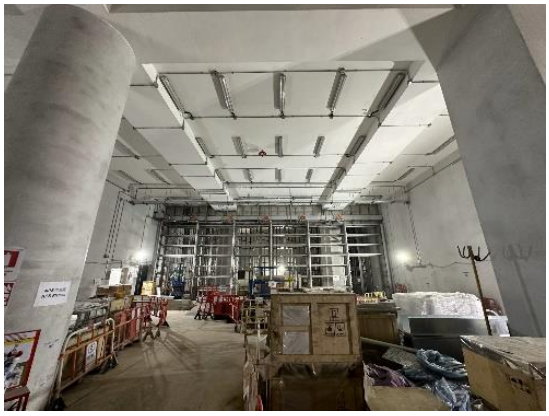
The area of the tunnel is actively being developed to repurpose the old Hong Kong airport for high rise housing, hospitals, and education establishments.

Vertical stacks would be an unwelcome addition to this urban landscape.

Attendance at the project sites revealed they are well organised and supported by known construction and engineering consultancies.

Installation of Air-Quality (formerly CTA) air cleaning technologies are progressing.

The standard of installations and equipment are high.



Installation of Air-Quality (formerly CTA) air cleaning technologies are progressing.

5.3.6. Guanqu East Extending Road Tunnels, Beijing

In September 2024 I inspected the Guanqu East Extending Road Tunnel at Beijing. The air cleaning plant has been installed for 3 years comprising both electrostatic precipitators and

activated charcoal gas purification. The configuration is 2 x 180m³/s plants, normally operated as a bypass system with an option to ventilate to surface in a fire emergency.

The installation was to a very high standard and all equipment was well maintained.

Observations in the tunnel itself suggest a very high air quality in the tunnel with almost no evidence of particulate residue on any of the tunnel furniture.

An inspection of the Aigner air cleaning equipment itself suggested that it has never been used.

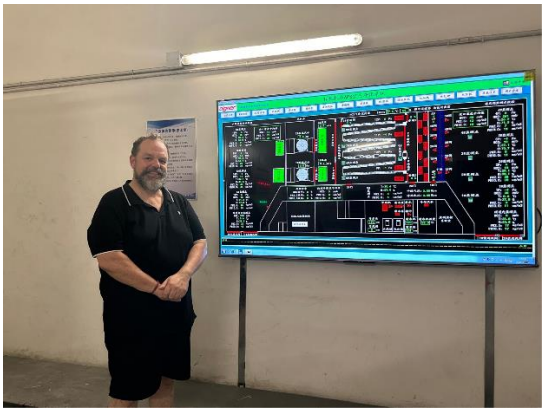
Above the tunnel is a park and not a ventilation stack. The park is an open community space with attention to detail. This is in Beijing – (September 2024)

This is the pathway by which technicians access the air cleaning stations below. Only in emergencies is air ventilated through ground level ducts in the park.

Under the park are three year old Aigner electrostatic filters. They are made from stainless steel and well installed. There is no evidence that they have ever been used.

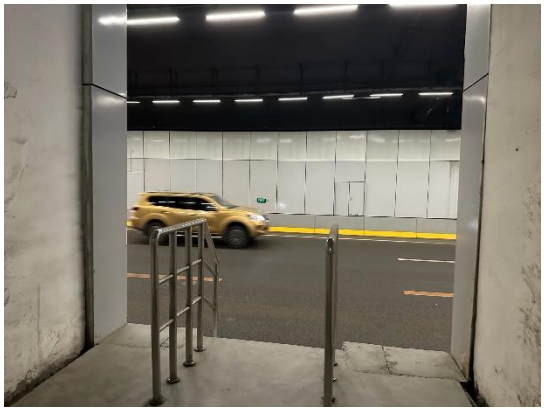
As part of the waste collection process, the slurry of collected waste is injected into a compression guillotine for water extraction for waste cake production. The fabric and all components of the cake production equipment are as new and unmarked. In my opinion the equipment has never been operated with a real waste stream.

Banks of activated carbon are meticulously installed in stainless steel bins. The bins, stainless steel, the floor and even the light fittings in this area are as new. In my opinion the activated carbon gas cleaning component of the installation has never been used.



The control systems and process schematics were of a high quality and indicated systems were ready to operate if required. There was no indication that the air cleaning systems had been operated.

The tunnel itself appeared immaculate with no tell-tale indications of pollution residue. This is consistent with the high air quality observed in Beijing generally and in the tunnel specifically.



5.3.7. Other mainland China installations

I was unable to inspect a second installation in Beijing - the Dong Liu Huan Tunnel that is reported to be 2 plants capable of processing 360m^3/s each. This tunnel is reportedly also fitted with Aigner air cleaning technologies.

Likewise, a new installation in Xian is reported to have been completed. I am advised it is operational, but I was unable to arrange an inspection.

5.3.8. Norway - Laerdal Tunnel

In 2017 I attended Laerdal Tunnel in Norway and can confirm that the air cleaning technology including denitrification is installed, however, is not used because of improvements in vehicle emissions. The air quality in this long longitudinally ventilated tunnel does not require air cleaning.

In Norway some 8 tunnels have ESP technologies installed into their tunnels – mainly for exhaust air and on average 50% for visibility. Only the Laerdal tunnel reports NO_2 technologies also installed for in tunnel air quality.

I did not attend urban tunnels in Norway for this study however I am reliably informed in 2024 that they are mostly no longer used.

5.3.9. Italy – Cesena Tunnel

Confidential enquiries of the installer of the Aigner ESP air cleaning equipment for the Cesena Tunnel advise that to his knowledge the equipment remains turned off. The equipment was required to obtain development approvals and installed in 2004. As at this time in 2024 I am reliably informed that the Cesena air cleaning equipment has never been turned on for operations.

Whilst I have been reliably advised there are two other installations in Italy at Sottopasso di Monza and Pozzano, I have not personally inspected these two installations and am therefore not in a position to comment on the use or otherwise of these two electrostatic precipitator installations.

5.3.10. Mont Blanc Tunnel

Aigner technology is used for particulate removal in the Mont Blanc tunnel. This is used to protect the residents of Chamonix from particulates from heavy vehicles using the Mont

Blanc tunnel to travel between France and Italy. The air cleaning technology was required because residents in Chamonix became especially distressed at the prospect of pollution in their valley from trucks when the Mont Blanc tunnel reopened after several years of closure following the catastrophic fires late last century. As at the date of this report in 2024 the air cleaning technologies are used only in winter to ensure the snow around the portals is white.

5.3.11. South Korea

Five South Korean road tunnels are reported to have ESP filtration technology installed – all are reportedly bypass type installations for visibility. Additionally, the Chinbu tunnel ESP is reported to also be, in addition to visibility, for cleaning exhaust air. The Chinbu tunnel ESP was fitted into a bypass tunnel by CTA in 1998.

Recent attempts to access the tunnels failed. Prior inspections (2008) revealed they were not operated.

In 2024 I was unable to gain access to the Chinbu tunnel for inspection.

5.3.12. Calle M30 Project, Madrid

The Madrid Calle M30 project was the most advance urban road tunnel in the world in 2008. Today it is apparent that most of the air cleaning plants are not used at all (some are used for spare parts), while at best one or two air cleaning plants might be used for an hour or two per day during the busiest periods of traffic.

Investigations and actual site inspections in 2018 suggested this is done for political purposes in order to avoid the allegation that the investment in the air cleaning plants were a waste of money.

The Calle M30 project is an extremely well utilised and heavily frequented set of tunnels.

However, when the author attended the tunnels and even during periods when the author was assured the air cleaning technology was being operated, there was no evidence that the air cleaning technology was being operated at all.

There was no evidence that the large axial fans which drive the air through air cleaning technologies were operating, there was no evidence of air flow, and there was the smell of motor vehicle pollution in the fresh air ventilation shafts, suggesting they were not pressurised and that in truth and in fact the air cleaning technology is not used at all.

Discussions with M30 subcontractors, government officials, consultants and the Calle M30 operator suggest the M30 air cleaning technology is barely operated at all – indeed some air cleaning stations have been closed (for spare parts) while others are either not used or used for an hour or so during peak traffic periods per day.

Given the politics surrounding the M30 project and the politics of air cleaning (given the stacks were removed from the design) actual operation of the technology is likely to ensure that if officials are asked about the use of the air cleaning the operator can say: '*the air cleaning technology is used when required*'.

In substance the massive M30 is being operated as a 100% portal emission system.

It is expected that the public justification for not running these technologies will be that air quality has improved.

Importantly no reference is even made to the air cleaning technologies in the Calle M30 Project in a key sustainability analysis in 2020[12]. Importantly, and correctly reference is made to the improved air quality in Madrid and the ventilation system used in the M30 project as a containment and dilution device.

[12] Abajo. L., Perez-Fortes. A.P., Alberti. M., Galvez. J., & Ripa. T., 2020: 'Sustainability Analysis of the M30 Madrid Tunnels and Madrid Rio after 14 Years of Service Life', MDPI Applied Sciences, Appl. Sci. 2020, 10(20), 7368; https://doi.org/10.3390/app10207368

6. Context of Study - Air Quality

6.1. Air Quality & Human Health

Tunnels should be designed to achieve high levels of environmental performance. I am not aware of any instance in Australia where this has not been achieved using properly designed and operated tunnel ventilation systems.

Each tunnel demands rigorous analysis of its likely air quality performance, and an appropriate ventilation regime designed, built, and operated.

The effectiveness of air cleaning technologies is no longer a matter of speculation – it is proven technology.

In some countries concern about the visual impact of vertical ventilation structures has driven both longitudinal ventilation options and in rare cases the installation of air cleaning technologies.

In most cities there has been a substantive improvement in air quality generally because of the stringent emission controls on the motor vehicle fleet and industry.

The effect of air cleaning technologies has an extremely minimal impact upon ambient air quality in the areas in which they are used. There is reluctance on the part of some governments to publish any data which demonstrates the lack of quantifiable benefit associated with the use of air cleaning technologies.

Philosophically the environmental dis-benefits (such as energy consumption and waste consolidation) should be balanced against the benefits of removing contaminants from tunnel air. Maintaining a balanced scientific perspective on such matters has been, and will likely continue to be, problematic politically.

Ultimately the technology does remove pollution from treated air. The question is one of value. Is the cost of installing, operating, and maintaining the air cleaning technologies worth the benefit that they create? This is a matter that can only be decided on a case by case basis and is peculiar to the country in question and the circumstances of the project at the time the question is asked.

6.1.1. Japan

In Japan air cleaning technologies were routinely introduced in highly congested, heavily polluted urban environments for both the removal of particles and in some instances the removal of NO_x. In such environments the value was in taking action because the air quality was so bad. Installing the technologies was considered appropriate given the poor air quality notwithstanding their price.

Air quality in Japan has generally substantially improved regardless of air cleaning technologies being installed. There is no administrative mechanism to determine when the technology no longer provides good value. In the absence of any administrative mechanism the Japanese authorities have no mandate to turn air cleaning technologies off despite excellent air quality being achieved generally.

6.1.2.Madrid

In Madrid the Calle 30 project extensively installed both air filtering for particles and in less frequent installations, NO_2 removal. In substance they are not used.

However, there is currently interest in making the systems operational because there is a new tunnel project which will likely have air cleaning technologies as a condition on the approval and the public process for that project has created renewed public interest in the performance installed air cleaning technologies. As was the case with the original M30 approvals, there is strong resistance to having vertical ventilation stacks due to their blight on the urban landscape.

6.2. Political Use of Air Cleaning Technologies

The use of air cleaning technologies as a technique to facilitate project approval (by alleviating public and regulatory authority anxiety) is often used internationally by tunnel proponents to gain approvals and public acceptance of projects. Although this appears to be an extremely effective political use of the technologies, investigations reveal that the outcomes for the community may be inferior to conventional approaches despite the subsequent lack of opposition to the projects by the community.

In particular, the fact that the use of such air cleaning technologies demands that they be activated in the face of global concerns about the inappropriate use of energy from a sustainability perspective – and that their use (or non use) is often not transparent to the tunnel users and surrounding community – means that operators in some countries appear not to activate them regularly or at all – without regulatory consequence.

Indeed, it appears many systems are not even maintained (usually on the basis that the cost to maintain is not warranted given the good air quality) but in not maintaining them there is no opportunity to maintain appropriate air quality as there are no dispersion stacks.

The presence of the air cleaning technologies is used as a justification for the removal of dispersion stacks (as seen in Madrid and Hong Kong). In the absence of both dispersion and air cleaning system activation, the consequences for the surrounding environment are likely to be inferior to that which would be achieved using conventional dispersion techniques.

In Japan where such technologies are used, they are combined with dispersion stacks and coupled with performance requirements. This is an honest and effective use of the technology.

The Japanese experience is that pollutants are reliably removed from tunnel air before being emitted to the environment. At the time these technologies were mandated urban air quality in the region was poor. As can now be seen, air quality has substantially improved. While pollutants will be removed any impact on air quality, with properly designed stacks and operational ventilation, should be at best inconsequential and in all likelihood nothing. In such circumstances the only benefit of using the technology is appeasing the local communities' fears.

In all installations issues associated with waste streams and maintenance are fundamental to the ongoing performance of the systems. In Japan these are well dealt with however in other countries a lack of attention to detail compromises the ongoing overall environmental performance of these systems – if they are operated at all.

I have not observed any air cleaning plants dealing with accumulated pollutants other than in Japan. In all other countries the systems are not used or if they are used, I have not been satisfied that the waste management process was as described in public documents.

6.2.1. Italy

Another example of the political use of these systems arises from the Aigner ECCO system which was installed into the Cessena tunnel in 2005. It was not integrated into the tunnel control systems until 2008 when the tunnel finally opened to traffic after several years (and at least one election) late.

No data is available on its performance. Again in 2024 I am advised that the equipment was never used. The equipment was installed to appease local politicians who were experiencing problems with their constituents in the lead up to an election to quell their concerns regarding the construction of the tunnel under the city.

6.2.2. World

There has been no instance of a sustained adverse impact being recorded by scientists and health professionals conducting the subsequent environmental and health studies of properly designed and operated tunnels anywhere in the world. Furthermore, general improvements in regional air quality are often recorded as the modelled benefits of improved traffic flow; reduced vehicle emissions and augmented route ventilation are engaged as part of the sophisticated management of tunnel air.

No government agency, consultant, contractor or authority produced any new information on the impact of tunnel air cleaning technology on human health or any study demonstrating tunnel air emissions from modern road tunnels was adversely impacting human health.

Furthermore, I am unaware of any air quality studies that demonstrate a health benefit from installing the air cleaning technologies in road tunnels.

7. Conclusions

A field based investigation of the use of air cleaning technologies in urban environments around the world indicates:

A. Internal engine combustion emissions controls are a highly effective means of managing particulate and NO_2/NO_x emissions
B. Emission controls on vehicles are the best way to manage air quality concerns
C. Air cleaning equipment is mostly installed to secure regulatory approvals and political support for projects
D. NO_x removal technologies are complicated to install, maintain and operate – with Japan being the only known country to regularly utilise installed systems

NO_2 removal technologies are installed in countries such as Spain, Chinese Hong Kong, Mainland China, but are not routinely used or maintained.

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

However, where air quality is poor, concentrations of in tunnel PMs and NO_x or NO_2 are high, or health risks cannot be otherwise managed responsibly, technologies do exist for the removal of motor vehicle pollutants from tunnel air.

World best practice for tunnel air health risk management is a combination of:

(a) Vehicle emission controls
(b) Management of in tunnel air quality
(c) Proper design and operation of tunnel air dispersal points such as portals and vertical emissions structures

8. Appendix A – MEC Japan Questions (confirmed in 2024)

A. What volume of air do you treat in each ventilation station?

In Yamate Tunnel expanding to 36km (18km), there are 13 ventilation stations. Average volume of treatment per station is 1 million and 300 thousand m^3/h ($362m^3/s$).

B. What is the mass/particle removal rate for PM_{10}, NO_x etc.?

Treatment performance is as follows:

Subject	Daily Average (%)
SPM (Suspended Particulate Matter)	80% or more
NO_2	90% or more

C. Is there data on air quality before and after the plants?

Yes. There are monitoring results of environmental impact assessment. These are collected at monitoring posts installed by municipalities in places.

D. Are there external air quality measuring stations?

Yes. Those monitoring posts of municipals make measurements. We also have three monitoring posts installed along Yamate Tunnel.

E. If yes to "D", do they record any difference in ambient air quality?

Yes. Monitoring results of environmental impact assessment show the difference. Regardless of location of ventilation stations, atmospheric environment in Tokyo demonstrates a tendency of improvement generally.

F. What is the energy consumption?

One station (of those above mentioned) uses approx. 43kW/h.

G. Have you been able to measure any political benefits of the technology?

For question G I am referring to the community and its reaction to implementation of the tunnel. There is often a political benefit from such projects. That is the political benefit I am referring to – a happier community not complaining to the government.

Generally speaking, even though environmental standards are satisfied, there are cases that local governments along expressways request the road administrators (expressway companies) to install NO_x removal devices in order to mitigate local environmental impact around ventilation stations.

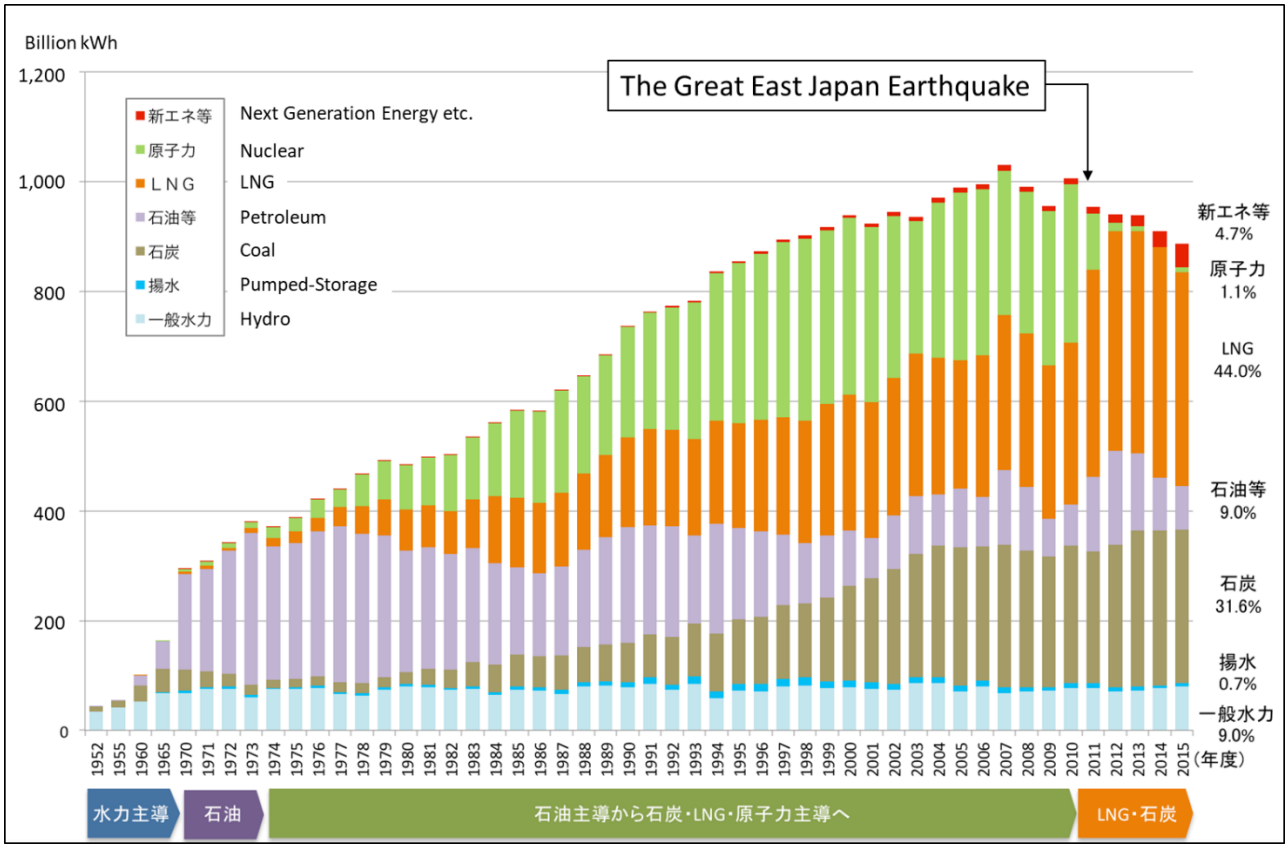
This can help local people around the ventilation station get a better understanding, and facilitate consensus building between expressway companies and local communities. Consequently, early opening of the expressway can be realized.

H. How do you generate your electricity? (Nuclear of coal or?)

We use commercial electric power supplied by electric companies.

H. How do you generate your electricity? (Nuclear or coal or?)

Figure: Amount of Supply of Energy and Power Generation in Japan



I. We burn coal. Do you think that is a relevant matter?

Yes.

9. Appendix B – Japan, Tokyo

Fuji are the proponents of electrostatic precipitators installed in some of the Shinjuku tunnels. I inspected their installation at the Yamate tunnel, and it was here that the Nishimatsu NO_2/NO_x removal system was first identified by the author.

To my knowledge it is the only self regenerating NO_x removing technology available in the world.

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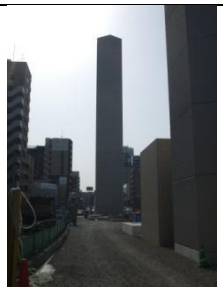
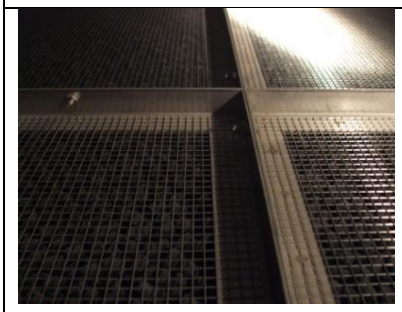
<tr><td>  </td><td>  </td><td>Ventilation towers along Shinjuku route. Note spatial relationship with accommodation towers.</td></tr>
<tr><td> 
</td><td>  </td><td>Self regenerating NO_2/NO_x removal system (installed but not operating) previously unknown to author.</td></tr>
<tr><td>  </td><td colspan="2">Activated carbon in NO_2 removal system. This is almost exactly the same as the systems in Madrid.</td></tr>
</table>

10. Appendix C – Publications on Tunnel Air Cleaning

Published Paper:

Atsushi Katatani. A., & Dix. A., 2011: ***Ventilation and Exhaust Purification of Motor Vehicle Tunnels in Japan***, BHR Group 2011 ISAVT14: Bedford, UK, 2011, P577-588

https://www.scribd.com/doc/242261457/A-History-of-Tunnel-Air-Cleaning-Technology-in-Japan

Dix, A., & Katatani, A., 2010: Balancing the Environmental Benefits of Removing NO_2 from Road Tunnel Emissions with the Environmental Consequences comparing Fossil Fuel and Nuclear Driven Power Stations, （May2010)

https://nanopdf.com/download/balancingenvironmentbenefitsv2201005054_pdf#

https://www.scribd.com/document/209308615/Balancing-Environment-Benefits-V2-2010-Katatani-Dix

Dix. A., 2022: The Cancer Risk from diesel Emissions in Underground Works, Tunnelling Journal Oct/Nov 2022 Edition,

https://pinssar.com.au/wp-content/uploads/2023/02/Particles.pdf

Dix. A., 2020, ***Air Cleaning Technologies for Tunnels - Honesty is the Best Policy for Protecting Human Health***, International Journal of Civil Engineering and Technology (IJCIET). 11(1) January 2020, pp. 318-328. ID: IJCIET_11_1_032

https://iaeme.com/MasterAdmin/Journal_uploads/IJCIET/VOLUME_11_ISSUE_1/IJCIET_11_01_032.pdf

11. Appendix D – Transcript of Meeting in Japan 24 January 2018

Meeting participants were from Japanese Government Agencies:

AD: I am a scientist and also a lawyer, and one of my jobs over the last 20 years has been protection of human health in relation to underground infrastructure. One of the issues for health in underground infrastructure has been pollution from cars and redistribution of that pollution in tunnels. Back almost 10 years ago now, I was the chairman of the Permanent International Association of Road Congresses – PIARC – report into air cleaning and tunnels, and we did an international survey of what was best practice as well as looking at medical and environmental issues. When Shinjuku Tunnel was being built, I came – before all of the cars – and looked at it. I also did a joint paper with Katatani from Matsushita Scientist on the experience of air cleaning technology in Japan.

My first observation, as a visitor to Tokyo, is that this is a different city than it was when I came 20 years ago, in terms of air pollution. Congratulations – I do not know exactly how you did it, I have some ideas how you did it, but the transformation is completely astounding and this morning I watched the sun come up from my Hotel and took pictures across Tokyo with the mountains and the snow in the background and 20 years ago this was not possible because of the pollution.

Today, in Australia, we are building, something like 60 kilometres of underground expressway and some of the communities are demanding air cleaning in the tunnels. So, before any decision is made about the air cleaning, my government, asked me to come and check what is the current experience around the world, so I am visiting one of my favourite tunnels around the world, Sinjuku. After visiting you here I will be going to Hong Kong to look at the new tunnel there with the Filtrontec air cleaning technology.

Thank you for seeing me and I hope that is a good introduction, so you know I am scientist, engineer and lawyer – all together.

INT: 368 tunnels in service ….. There are 18 kilometres. Very long tunnels.

AD: Tokyo Bay tunnel – very famous tunnel.

INT: Yes. A special structure but I do not know any issue. The tunnel is going under. A pipe like.

AD: Ah yes, immersed tube.

INT: Yes, immersed tube. Now we have a constructing sections here and here

AD: So, Yokohama, Circular north eastern route – so this is new tunnel?

INT: Yes

AD: And other one? [noises sound like map reading] So more near city? What is this one called?

INT: Horumi Tunnel

AD: Are you putting air cleaning on this tunnel or other new tunnel?

INT: No, no this section is not a tunnel.

AD: Oh, just new road.

INT: Around here and around here we have a treatment.

AD: So, you do have? So, in this new Yokahama you will have treatment?

INT: Yes

AD: Ok. And is that because protecting the local environmental, like the trees and things? Or protecting peoples' health? Or, do you know the main reasons? Or politics?

INT: [Politics]

AD: … I should explain – in Australia we have the science and the engineering, and we have the politics. The two are not the same and so we will make decisions for political reasons if this means the project can go ahead. Even if the science is bad.

AD: So, it's the same? [In Japan]

INT: Yes

AD: So, we know as a government that the best thing is to control the pollution from the vehicles. So, emission controls, these sorts of things – but – sometimes the community are very angry. So, we say OK

INT: Same type. [Same situation in Japan]

……

INT: Is there any other question about answers – please

AD: That removal weight is on a mass basis or on a particle removal basis? Is it how heavy – or number?

INT: By counting the particle. Just for the particle we measure. To verify the parameters of the device we also measure the particles by weight. Measuring by weight is very difficult. We do not usually use measuring.

AD: The NO_2 extraction of 90% or more – this is like newer technology, are you finding the NO_2 technology reliable? The particle removal – this one – is old technology. Maybe 30 years. But NO_2 technology is more recent. What is your experience in this NO_2 removal technology? Is it very reliable?

INT: In regard to the process introduced 10 years ago. So, there are studies from before that case, but government and planning sectors studied about this technology it's the first case with the installation. So, it is a recent case.

AD: I remember when I visited last time there was a competition between Matsushita, Kawasaki Heavy Industries and they were both saying "my one is very good"

INT: In the time of the government initiative many companies develop the technology but actually there is just 2 companies that could serve the technology to the expressway and that was Matsushita and Nishimatsu. Only these two companies.

AD: In the end which technique for NO_2 removal did they decide to use? Because, if I remember, the competition was also about process. Some had activated pads with catalysts, another one had, I think it was, activated carbon. There was many different ways.

INT: The performance of any type of visit we can accept. For the technology we considered for the budget and the maintenance cost in the future so this depends in this items.

AD: So, you have installed from both companies' equipment?

INT: Yes, yes

AD: Because we are government, we are interested to know your experience because we are also worried about if we install the maintenance, costs, waste disposal, vulnerability of the unit if for example the particle removal system fails and so we have particles in the NO_2 system, is this a disaster? Or is one stronger than the other? Just the practical, if there is a practical preference between the two or is it both some pluses and some minus but both OK? I am just interested.

INT: Because our companies are public companies, so as you mentioned we also considered about. We admit minimum politic line so after that we had to see what is the cost and the maintenance cost because this is very important so. Personally, preferred one company. To decide one company is better is to do the maintenance or after care. But we have no way to decide.

AD: That is OK. [So ….] you do have a preference but because you are a government agency you do not want to express it because that would be unfair and so for your purposes both of them perform enough, and then you can leave it to us to figure out which one it is.

INT: Yes

AD: Can I ask another question?

INT: Yes

AD: As one government to another, what in your experience are the important things for us to look for? Like what are the things that we should be looking at if deciding between the different technologies? Is it energy consumption or the cost of consumable parts within the machine? Or the waste that is produced by the machine, or how big is the machine or how efficient the machine is? What would be your advice to us from your perspective as a user? So, put the science to one side – just the practical things?

INT: Look at the performance. Then look at other sites. And there are many conditions so we request the company performance to admit their real performance so that is the most important.

AD: OK

INT: Without waste

AD: So, no waste?

INT: No, no, **less** waste

AD: Ah **less** waste, yeah. And so, is there an example of say the NO_2 removal, is there a minimum concentration of NO_2 in your experience that is needed for the machine to operate efficiently? Or it just works – no matter whether it is high or low concentration of NO_2? What I mean is if the air is clean, maybe there is not so much NO_2 – is it your experience that even if not much NO_2, still 90% more?

INT: We have our conditions the contract says under what condition, so [if] very clean air [we] exclude [the result]

AD: Oh, and are you able to tell me what is very clean air for you in Tokyo? Like what the limits are.

INT: Under 0.06 ppm NO_2

AD: Under that turn off or under that you do not worry anymore? Like do you turn the machine off under 0.06 ppm or?

INT: [We] Leave machine on but do not worry about it anymore. We select even if we get 100% we leave the machine on.

AD: Is that because it is easier to leave it on than turn it off? Like if you turn it off – then you have to turn it on.

INT: Most of Matsushita and Nishimatsu machine don't need electricity, so we do not.

AD: Just passive? So …. activated surface with catalyst …?

INT: Yeah

AD: And then that means you have to keep the particle filter on as well to protect the NO_2 cleaning plates?

INT: Yes, the ESP also called the dust collector. We have a system a ventilation system, so let the air in the tunnel, so treat the dust collector connecting and not connecting.

AD: So, with the air coming through the ventilation system – is that 100% of tunnel air, or 50% of tunnel air, or, how much of the tunnel air is being extracted?

INT: Depends on the pollution. There is a sensor.

AD: Yes, and if more pollution then the fans are turned up higher and take a bigger proportion of the air?

INT: The ventilation system for the tunnel is on circulator air in the tunnel so there is not a big problem, just the ventilation is OK. But especially for pollution we have a dust pollution system.

AD: So that I understand – the air cleaning technology is always turned on but the amount of air that goes through it depends on air quality in the tunnel. Does that mean that the speed of air that is going through the air cleaning technology changes? Like is it a fixed size ventilator that you put more and more air through or is it staged? Like you have first gear, second gear another third – more and more air but the velocity across the machine is similar? Or, is it just faster and faster, so the more dirty the tunnel air the more air through the machine and the faster it comes through the machine?

INT: To increase the sending air the machine has to increase the speed to a specified site, so we cannot downsizing the speed.

AD: Do you find that the efficiency of the machines change much for the air speed and the particles and also NO_2?

INT: According to the speed the air ceiling is down so we request the machine company to maintain this level of performance. The high speed – at the maximum speed.

AD: This was a big controversy years ago about the speed through the machine and some companies would build cells, like one cell, two cells, three cells – so a little bit of air one cell, more air two cell. So, the velocity was maintained, and some companies said no not a problem we can take very high speed, so I was wondering what your experience. I think you have answered that – you just have single one. Which companies are you using for the particle removal?

INT: ESP …. Matsushita and Fuji

AD: Ah yes, Fuji had NO_x removal as well, so they must have fallen off. So, Fuji for particle removal and Matsushita. And I think Panasonic. I think that is very interesting.

This looked like a simple question, but it was really a very hard question. Thank you very much for answering that. There won't be so many questions for the other one. This was the hard one.

AD: …. So, with monitoring of the environmental performance (C) and (D), has anyone detected any change in the air quality actually out in the community? This is number (E) – this is the answer?

INT: Yes

AD: So, I was ahead of myself. OK. Has there been any studies as to why the air quality is improving generally in Tokyo – like are people saying it is because we have air cleaning technology or is it when you look at the science is it because of the concentration on industrial emissions, vehicle emissions – actually the reduction in emissions and not the air cleaning? I am interested if there has been any examination of why the air is getting better?

INT: Mainly caused by the policy of the Tokyo government.

AD: Like removal of diesel trucks and things like that?

INT: Yes, and diesel emission. This and the reduction of emissions.

AD: OK, and normal powered vehicles like petrol powered vehicles, has that made an impact, like better emissions from them or mainly the diesel?

INT: Also, the gasoline car has a regulation on the emission. So, the main reason is the government policy for reduction of emission.

AD: I recall when the Tokyo government made it strong policy especially for inner Tokyo city there were headlines around the world because people thought it was crazy – but now I see the results. You have basically clean looking air. It looks clean, I do not know the numbers yet, but it looks clean. So, would you agree it is a big success now – the air quality?

INT: Yes.

AD: Yeah, so is it the same in other cities like Yokahama?

INT: Yes. 9 big cities in Japan - like a whole region.

AD: The same thing as it progresses with this policy improved air quality?

Male Voice: We started at the same time, as a compilation.

AD: OK – this really leads into (G). The political benefits and you wrote to me and said, "what do you mean by political benefits?" And then I wrote back and said not the science but the political feel, the community reaction, acceptance of the road infrastructure. And you said actually governments asked you to put in the NO_x removal to minimise local impact around vent stations. Is it actual impact or the perception of the impact?

INT: Perception.

AD: Ah, just strictly between our governments. With the electricity that you use for the technology. I asked if it is from nuclear power or from coal, fossil fuels. I asked that question because of the pollution generated by fossil fuels – and you say that you think it is important that if we use coal to make our electricity. Can you explain what you mean by it being important? What I mean is if in Australia we use coal, fossil fuels, to make our electricity – why do you think that is important, whether we use air cleaning technology?

INT: As you see by 28th the nuclear energy was increasing. After the great earthquake to Japan and the power station accident.

AD: Yes, when I look at the graph it shows a little bit of nuclear coming back.

INT: Most regulation of the nuclear station for condition of the nuclear station working is have been restricted. Some stations have cleared the level, so they began to work again.

AD: … [What is] next generation energy, it is increasing, what is next generating energy?

INT: Solar power, wind and geothermal.

AD: But not pump storage? Pump storage is separate. I think that is excess power pump water up in the mountain then hydro.

INT: Traditionally we used to do this in the night. This pumping. We used to use this power before the solar power and wind.

AD: We have just installed a very large battery power storage facility in Australia. It will be interesting to see how that works because it is similar to pump storage – when there is excess power charge the battery farm and then when we need power, take the power. Anyway, I am not sure how that will go.

Is there any development in plasma reactors here? Is Japan looking at plasma? It is like nuclear fusion – nuclear together, not nuclear apart.

Male: It is called plasma?

AD: Yes, plasma. You have an electronic field and you have the hydrogen inside and the energy comes together like the sun. Maybe not. Europe is trialling a new reactor like this, a

plasma reactor. I was curious that is all. It has nothing to do with what we have been discussing. Because if the plasma technology comes then the graph just goes plasma because it is the energy of matter. Not like a nuclear bomb but like the sun. So, it is different.

So, can I ask you another question. With the energy consumption of your air cleaning stations at 43 Kilowatt hours, is that just the energy for the equipment or does it include the energy for the fans to pump the air through the air cleaning device. So, is it 43 kilowatt hours for 1,300,000 m^3 per hour? So, is it the figure to do that? So, is that the figure for the machine or is it for the machine plus the fans to put the air through?

This is the capacity of a vent station. (sounds like you are looking at something)

INT: Yes

AD: And this is the energy consumption

INT: Yes

AD: Is that the energy consumption when the station is pumping this much air or is it the energy consumption no matter how much air?

INT: This is an average. According to # the first option is, this other # is for the SPM detector at the maximum.

AD: OK and that's the consumption just for the particle removal part of the machine or is it the particle removal part of the machine and the electricity used to take air from the tunnel and push it through the machine? Or is the fans not counted because it is part of the vent system?

INT: No, not including the fan.

AD: OK. So, does that mean that as the air speed increases in the machine the voltage across the plates is increased to increase the efficiency of the machine? If the energy consumption increases as the amount of air increases, is that what changes, more electricity to?

INT: Yes. But it depends.

AD: OK – I understand. Do you have to replace the plates or the whatever's in the NO_x removal system, do you have the replace those things?

INT: … we have a problem to remove the particle removal machine, so we have a program to renew the components.

AD: OK so is that a manual job where you have to physically go and move the parts?

INT: It depends on the type.

AD: OK – and which one does which? Back to my first question I am thinking.

INT: There are two types of machine. They carry the machine in the factory so they check-up the machine. They check out the one type and bring it back to replace.

AD: So, there are two machines. They take the one in service out and take it to the factory for maintenance and put the number two machine in to operate while the number one

machine is at the factory for maintenance. And then the other company comes and maintains at the site?

INT: On the site – they do cleaning on the site.

AD: OK. Do you have to turn the ventilation off to the equipment while you are doing the cleaning?

INT: Yes

AD: How long is it turned off for?

INT: Working time – I am not sure about the time. Maybe one night or maybe one half a day. Cleaning type two or three hours required.

AD: And cleaning type – can people who are not from the company be trained to clean it or does it have to be people from the factory that comes to clean it. So, for the cleaning type can you train your normal maintenance staff to clean it or do you have to have the company come and clean it?

INT: They do the cleaning automatically of the machine. Have a maintenance contract from the company. Simple cleaning, we do.

AD: For your criteria for the different companies, was of the criteria's the cost of maintenance? Like for both companies, is it like the money cost in the end about the same or different? If the cleaning is from the company for both types is the cost from the company for both types about the same or different? Like is it more expensive to clean it in the factory or more expensive to clean at the site?

INT: We never compared about that kind of cost.

AD: I have to ask the companies and see what they say. It is interesting for me – I think what you are telling me is that you need the company here to service the technology. It is like you buy a Toyota you need Toyota to fix the vehicle. It sounds like your technology also needs special company experts.

INT: All of the staff can diagnose a simple problem. For detailed or the important matter another company does not deal. So, like you said we have key obligations by the provided company.

AD: And does the provided company take like the waste or the chemicals? You said it was cleaned every day. With the waste that is produced is it something that has to be taken away? Some type of waste as well?

INT: Yes, yes, basically.

AD: So, this is not your problem. It is the company.

INT: We know how to use the produced company. We have a maintenance company and the provided company has a maintenance.

AD: For the particle removal machine do you use a particular company or a range of companies? I think you said Matsushita, Fuji, do you have any Kawasaki machines, or no Kawasaki machines?

INT: Another company Mitsubishi Family Company – not Heavy Industry. Firstly, they did not develop the machine but now they do from their company.

AD: Ah that explains. When I knew I was coming I emailed by friends at Mitsubishi in Kobe – no reply.

INT: No. After the competition – 3 companies we now use Matsushita, Fuji and Mitsubishi.

AD: Not Kawasaki.

INT: No for removal.

AD: …. you have 10 years' experience with the technology. Is there something that you think I should know, something that is not here? As a government – one government to another? Not in sales.

INT: You say 10 years' experience but technology itself has been developed since 1990 – too many years. We hear many companies beside the 3 have this type of machines in development. There is no a reason for this technology is a requirement but once the technology is built not how we thought, not so many companies are respected in this industry.

AD: I think you are right it is a very niche technology. What do you think are the key features of this niche? Like what do you need to make this technology work?

INT: Depends on the purpose for which it is built. There was companies that were to reduce air pollution, but Japan now has a requirement, so we don't need that amount of technology industry. Overseas, another company maybe they need.

AD: So, it is just for special cases where the pollution is especially bad or where it is needed for the community.

INT: Both reasons.

…

12. Appendix E – Madrid Calle M30 Contractor Interview 2018

AD: When I was down in Madrid recently both Aigner and Filtrontec told me, they do not have the maintenance contracts for their installed air cleaning systems or actually for anything on the M30 anymore.

SG: Yes, yes

AD: They said that Ferovial might have some and maybe you guys, Contractor, have some involvement – maintenance contracts there as well at some time

SG: Yes, that's right

AD: What happened, do you know whether those air cleaning plants were used, or used a lot or used a little bit, do you know anything at all about what happened?

SG: As far as we know they are not being used too much. This is also very sensitive matter because this is elections and expensive installation and they were installed in the time of 2007 and there was some politics in the middle. In terms that they want to build the most advanced tunnel in the world. It does matter to be the biggest at that time with the latest technology. So, they installed all the latest technologies and one of the technologies they installed because it was, and they did not want to build the shaft with the exhaust fumes will produce a lot of pollution coming out of these shafts, so they decided to install as well these air filtration units. Electro statics filters, no. Um, ok based on that they installed it. They also wanted to compare the different technologies because it was approaching to everyone from Filtrontec form Germany, Aigner from Austria, also Panasonic from Japan and they installed a biggest and a big portion of the filters were Aigner and a smaller portion was Filtrontec and Panasonic some small portion. We have at that time at the time of the complete a contract for the Aigner filters from Austria. It was under our scope. It was installed, commissioned and everything was fine.

AD: Yep

SG: And operation. As far we know the operation of course related to the power consumption and it was quite high. So, they don't use unless there is really a lot of pollution and how I tell you it is a little sensitive because the politicians they say 'we spend a lot of money and now we don't use and so it has to be used and we must use and that is why the political one that we don't say

AD: I understand. When I was there the operator was there and I said can I have a look and they said yeah. So, we went down into the tunnels and the first thing I notices was that the axial fans were not running. So, it would be pretty hard for the filters to be running if the ventilation was not running and then I went under the deck – I went into the section near the control room which is the special touristic, nice paint on the floor, very beautiful

SG: Yes, like a beautiful, big room with all the screens. No, so you were there, in the control centre?

AD: Yeah, and so because, you know, and I know, and they don't know that I know, so, I walk around, and I see that there is no air quality data on the screens, right? There is

nothing. So, I don't say anything and then I go can I go down and have a look and they say, yeah. So, we go down and go under the road and then through the tunnels

SG: Yes, and then big shaft, no? Right? Big and then round metallic?

AD: Yeah, very impressive actually. Great piece of engineering. Well, the first thing I notice then when I am in that shaft is that there is no noise. And so, I thought my goodness – the big axial fans must be these special no noise axial fan … [laughing]

SG: You know, we are good, but not so good

AD: Yeah, good but not that good. And so, I don't say anything because I am not there to cause trouble. Just to find out quietly what is going on. Then I went down to the road deck level then down to the lower deck level.

SG: Yeah, it's a double deck, no?

AD: Yeah – and so they have got the little vent air ducts along the side and I am smelling the air and the air is, I can smell pollution. I don't say anything, but the design concept is for the fresh air to pressurise down there.

SG: Yes, yes that is right. And at this time is your visit, is like called the bypass which is like TBM, is like 5km and with double deck it is pure transverse ventilation system. The transverse is to take below the road and then take through some openings to the level of the traffic on the motor side. On the top there is another false ceiling with dampers, and there is suction of the fans and then that goes through the fans and the shafts and up to the ventilation units. The electrostatic units. So, the design, concept design is made is that everything is perfect. The thing is that the operation is so much traffic at this time they say. But I say to you that my thinking is that the traffic is still quite high, and the electricity is too high and so they keep it operational, but they don't operate so much the units. Finally, I say, I know that the operator was using when needed but now not so much. We have the maintenance package for the complete ventilation package of the whole M30 which involves over 100 fans. Many jet fans and many big axial fans in the shafts where you went down. Where you went there is 8 fans in this shaft. 4 big vertical and another 4 vertical for exhaust for fresh air. And the filters in 2007 was already for the maintenance package watching the filters in the quality period but from about 7 years ago the filters were not maintained anymore and is now a different company. We do the maintenance of the fans and dampers and the ventilation equipment but the filters is not now in our scope for the maintenance contract. This is our situation there.

AD: Yes, it was interesting because I was in the lower deck and could smell the pollution from the cars. So, I put my hand up on the little vents on the sides that have the plates to adjust the flow and there was no air coming in. Which is consistent with the air being turned off and is consistent with what I can smell. And then when we went upstairs, and I said to the guy, 'and how much do you run this', and he said, 'we run it at 5%'. I said, 'what would 5% do' and he said, 'we are running at 5%'. I said, 'if it is for air cleaning you take – 5% of the downward air

SG: If he is saying 5% of the fans it is not possible because it is so low a speed that the fans will not run. It is a rotation that they will not even move air. Probably he has not too much idea.

AD: Yes, he is a traffic manager and not a tunnel ventilation expert.

SG: Yes, the managers there are more into traffic management and more into safety. Not, they are good. Many times, I take visitors there – maybe 50 times. I have seen an accident when I have been there, and they manage that and the traffic very well.

AD: Yes, the air treatment is not their focus. When I spoke to Filtrontec they said some of their installations were turned off and just used for spare parts and so that was interesting. And when I spoke with Aigner – I gave Heinz a call.

SG: Yes, we also have a very good personal relationship with him.

AD: Yes, he is very straight forward and very direct. He said yes really – he was going to check – he said he does not think it is very much used. I took a picture of the supervisor control centre and it was indicating about 1,000 hrs on that plant, the one near the control centre. That could be right about 1,000 hours over a 10 year period.

SG: Yeah it was commissioned in 2007 and in our contract. So, it is already 10 or 11 years running.

AD: My clients' just need to know the truth of what is going on.

SG: Yes, so this may be an example of the study. What they do in Madrid is they make the ventilation system – that they want in 2007 and now what they can offer. And the reality of this thing, yeah maybe? It may be true that in 2003 after the level of the traffic was crazy and reviewed and they make this decision.

I forgot to tell you that we supply a big project – one tunnel, very very iconic and important one that they want soon by-pass in Hong Kong island in front of, they want bypass from central to wan chai bypass. If you are in Hong Kong island and you are near Wan Chai the main contractor is Leighton – maybe Australia. And we supply all of the fans and they have ventilation air filtration units that are huge. Ah, Arnold! I was visiting there, and they have a cavern underground with a huge air filtration from Filtrontec and we supply the fans with a contract with Leighton. And Leighton's they supply the filters, so it might be interesting to you have a look. Operating in a few months in Hong Kong. They are installing. There is also a new project in Hong Kong called TKO it is many tunnels like – they are leading for Asia. They are thinking in 2018 (designed 2 years ago) they are installing air filtering – I was impressed by the size and the ground covers they have to make for the electrostatics and Filtrontec in that case is the supplier and also for the carbon activated for the NO_x and the No and the particles. The philosophy of this area is that with very congested traffic and the polluted smoke is to be exhausted through shafts and in this very expensive area their apartments are in this area. If you can afford an apartment you do not want to get cancer from living there. There is a lot of interesting subjects.

SG: Politics, the approach here is for political. The people do not want theses installations as they don't want to get the cancer. The exhaust shaft they say the implication

costs very high. Like in Prague they make all of the considerations, but they know the cost and then they say no and make the ventilation shaft somewhere not near the people. It is not nice to have chimney near you.

AD: We know as engineers that dispersion from a stack is OK with the pollution spreading a long way diluted. Less cost of this than filters.

SG: Construction limited by area available make all projects different for consideration. In Madrid they said for sure. After they know the traffic in 2004 and then the election coming in 2006 and the commitment was made. Amazing no? It was important for the politics and the financing will last a long time. The Politician at that time it was good for his career to execute this project in such a short time. Probably the Hong Kong case is quite quick.

AD: Yes, but they collect all the air and the NO_x and when the air is release it converts to NO_2 but they do not tell anyone about that. And the developers are actually behind it because they thought that putting up a dispersion tower would look bad and block views, so they, and also China's blue skies policy to help with air quality.

SG: Yes, if I have to make the decision today after the investigation I would not install. Thinking about the cost, I sit down with the consultant in Hong Kong, there is a British guy there following the project – they will make the space but the decision for air cleaning being installed is not clear. The future there is sure electric cars. This will mean less need for air cleaning. Still needing ventilation systems but different to innovate.

AD: Yes, to be able to separate the dirty air, the pressure drop – this is where the future might be, not on air cleaning. Maybe a new duct system will come soon. The energy conversion of movement of air and the protection of a duct and actually have the energy transfer down in the tunnel that is an innovation design that is not hard to maintain as the difficult parts are up in the ducts that we can get access to. But we actually deliver the air in a lower cost nothingness down in the tunnel.

Email from Contractor 22.4.18: Since the opening to public of M30 tunnels, around 10 years ago, Contractor is taking care of the tunnel ventilation equipment maintenance (i.e. over 1,000 Nos. Fans with their Dampers, electric panels...). **Air filtration systems are excluded from our scope, as they are considered a separate equipment package; their maintenance have been awarded to a company called FERROSER, belonging to Spanish contractor FERROVIAL.**

Every two years, since the beginning, Contractor

has been renewing its maintenance contract. We have a fully dedicated team of 6 skilled Electro-mechanical engineers to carry out this job. During all these years, M30 has shown a

high level of satisfaction with (contractor) Maintenance works, and none major incident was reported.

Regarding your request about any information as to equipment's performance, unfortunately we do not have it, as our duty is to keep the ventilation equipment perfectly maintained and in operative conditions. Obviously, the responsibility to run the ventilation system belongs to M30, also they decide under what congested traffic conditions the air filtration system has to be in operation; as far as we can see the system does not need to be intensively in use. I'll try to get any information on this matter (if available) and get back to you.

For my understanding, your query about studies or public information on the cities air quality is mostly focus in Madrid M30 project or in Spanish Main cities in general.

On the other hand, regarding Maintenance of tunnel ventilation equipment in urban transportation infrastructures, we would like to share with you that (contractor) has been prequalified by TfL (Transport for London) for bidding the Maintenance works of the tunnel ventilation equipment in CROSSRAIL (now named as Elizabeth Line). Sure, you know about this new Underground Railway line being executed in London, where (contractor) have supplied the tunnel ventilation.

13. Appendix F - Madrid Air Cleaning

Prior to the Global Financial Crisis ("GFC") Spain was experiencing unprecedented economic growth. Spain had committed to an ambitious recovery program based upon significant investment in all aspects of transportation infrastructure. This included extensive underground road and rail developments within Madrid and other regional centres as well as surface expansion including high speed rail into France. Spain had been advised by the EU that it must address environmental issues or face financial penalties imposed by the EU Parliament.

Spain's M30 ring road project in Madrid was one of the worlds' largest and most ambitious urban renewal programs pivoting for its success on 56 kilometres of tunnels for its nearly 100 kilometres of new road. The total project budget was around €3.9bn.

Early designs of the underground components of the project included vertical stacks for tunnel air dispersion. Design for the project began in 2002 however the originally designed vertical stacks were vigorously opposed by the local community and ultimately removed from the project on the basis of the air cleaning technologies.

Early Spanish tunnels had full portal emissions. Areas around the portals were polluted with discolouration to buildings and generally poor amenity observed during several field inspections by the author in early 2003.

Furthermore, the ventilation stacks were seen as visual amenity. The original ventilation stacks were likened to cooling towers from nuclear reactors by opponents to the project.

At a national level Spain was under significant pressure from the EU to implement environmental improvement programs or face significant reductions in direct EU funding.

In this context the removal of the ventilation stacks and use of air cleaning technologies provided an effective approach to facilitating project approvals, project delivery and maintaining EU funding within the election time frames of the incumbent government.

The objectives of the M30 project were:

- An increase in the capacity of the M30
- Recovery of the environmental area surrounding the old sections of the M30 (estimated to be some 30 hectares)
- Regeneration and clean-up of the Manzanares River
- Improvement to radial connections surrounding secondary roads
- An estimated annual saving of 4.4 million work hours for improved journey time (economic value of the next 20 years to be estimated at €190M)
- Reduce the number of motor vehicles accidents (this is estimated to be in the order of 15%)

- Lower noise pollution (vehicles travelling underground)
- Reduction in vehicle pollution by:
    - Reducing fuel consumption as more direct routes will be available
    - Reducing congestion of traffic
    - Installation of air cleaning systems to filter tunnel emissions.

The reduction of pollutants emitted into the atmosphere has been estimated to be 1,750 tonnes per year.

The general layout of the section of the M30 project with the air cleaning technologies is depicted in the following map. Also shown are details of the manufacturer of the various technologies used.

Air Cleaning

Ambient air quality in Madrid was generally poor. Exceedances to air quality goals were regularly experienced at most air sampling stations prior to the M30 opening.

Limited air quality analysis was conducted along the proposed route of the new roadway however existing highly congested traffic flows are thought to have compromised the usefulness of this data. Unreported testing since the tunnel opened demonstrates that the ambient air shed is in much the same condition.

	*Top of ventilation stack is visible in bottom left of photograph with housing across the valley. Earlier inspections revealed banners of protest against the ventilation stacks on the balconies of the housing – now removed.* Located on South Bypass.

Overall, the project delivered a vast improvement to the visual amenity and public amenity of the corridor under which the tunnel system now operates. Independently of the air quality issues the project is considered an overwhelming success. This view is also reflected in the media.

There was little evidence that the air cleaning technologies are being used (at all) and it appears that most emissions are exhausting via the portals.

Summary of Vent Stations

In the West section of the project:

- 8 ventilation stations without EP
- 8 ventilation stations with Panasonic EP

- 3 ventilation stations with Filtrontec EP

On the South Bypass (4 kilometres):

- 2 ventilation stations fitted with EP and De NO_x by Aigner
- 2 ventilation stations fitted with EP and De NO_x by CTA

At the junction of the M30 and the A3:

- One ventilation station fitted with EP by Aigner

On the Avenue De Portugal (2.3 kilometres):

- 3 ventilation stations fitted with EP by Aigner

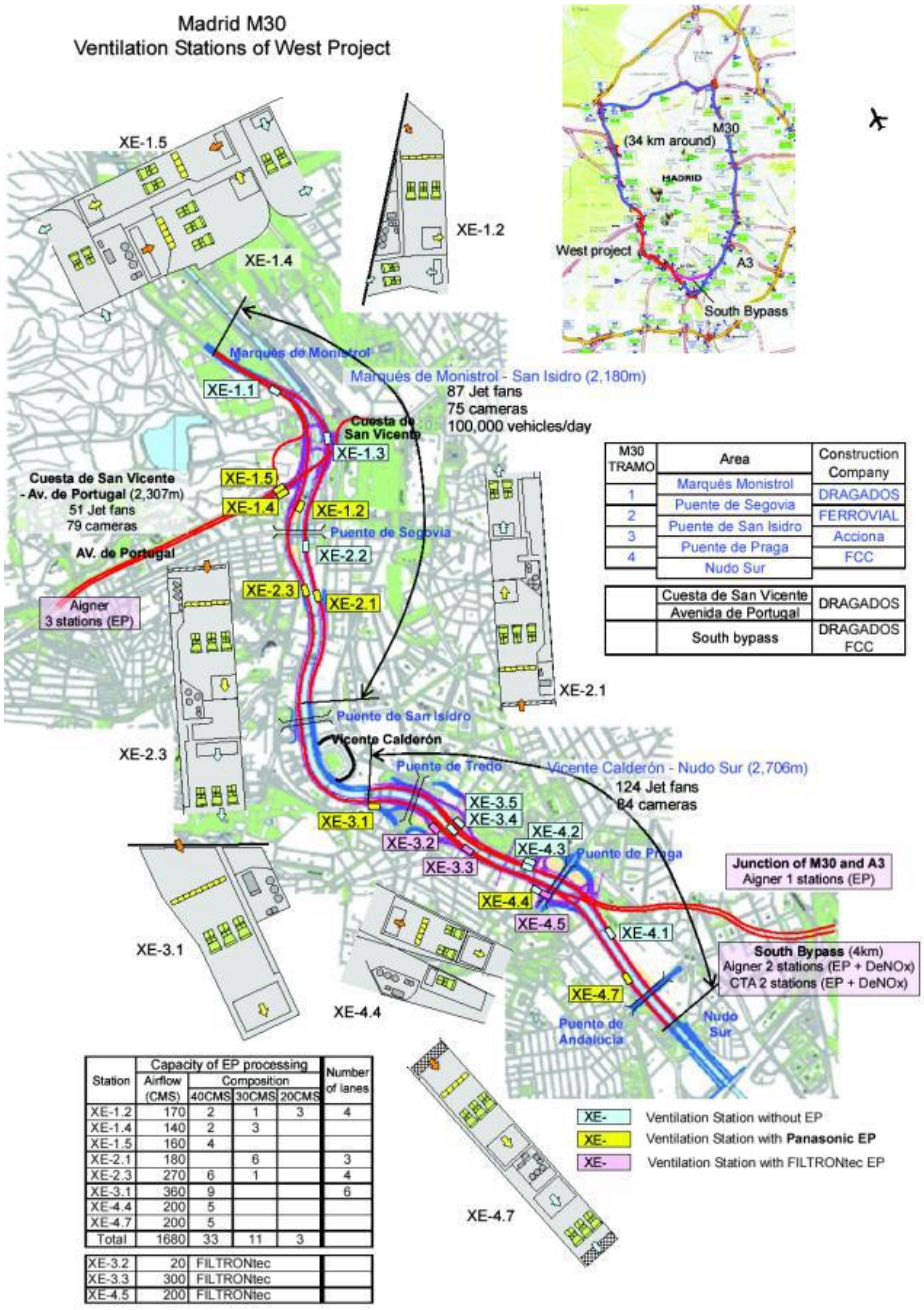
A summary of the number and location of air cleaning stations in depicted on the following map.

Operational regime –

The system at best is run intermittently only on a manual control. Requests for inspections of actual installations were declined.

The system is not integrated into the tunnel control system.

Cost – not disclosed.



M30 TRAMO	Area	Construction Company
1	Marqués Monistrol	DRAGADOS
2	Puente de Segovia	FERROVIAL
3	Puente de San Isidro	Acciona
4	Puente de Praga	FCC
	Nudo Sur	

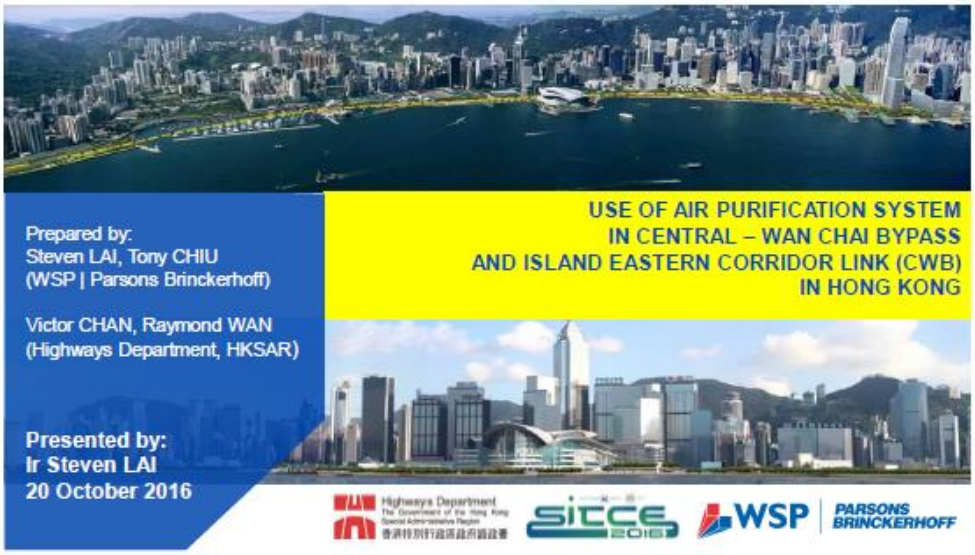
	Cuesta de San Vicente Avenida de Portugal	DRAGADOS
	South bypass	DRAGADOS FCC

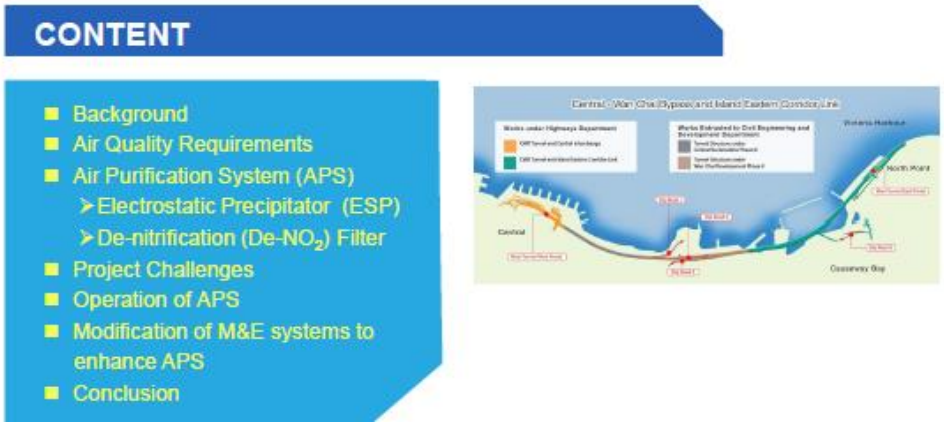
Station	Capacity of EP processing				Number of lanes
	Airflow (CMS)	Composition			
		40CMS	30CMS	20CMS	
XE-1.2	170	2	1	3	4
XE-1.4	140	2	3		
XE-1.5	160	4			
XE-2.1	180		6		3
XE-2.3	270	6	1		4
XE-3.1	360	9			6
XE-4.4	200	5			
XE-4.7	200	5			
Total	1680	33	11	3	

XE-3.2	20	FILTRONtec	
XE-3.3	300	FILTRONtec	
XE-4.5	200	FILTRONtec	

14. Appendix G - Hong Kong PowerPoint Presentation

Provided to the author at an in person interview in 2018 in Hong Kong

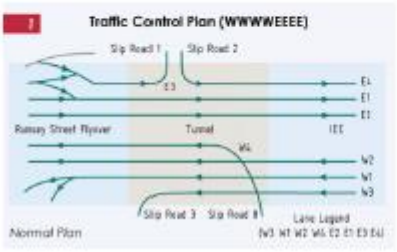


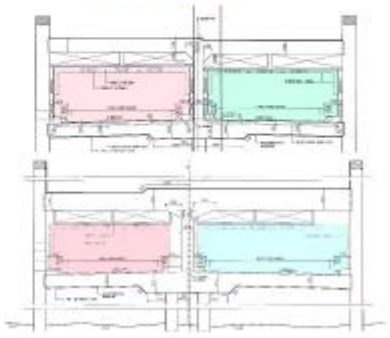


BACKGROUND

Tunnel: 3.7km
Dual 3-lanes
4 slip roads

Traffic: Uni-directional
Bi-directional





BACKGROUND

2001:	Initial Environmental Impact Assessment
2007:	Final Environmental Impact Assessment
2009:	Environmental Permit to Construct (Approved)
2009:	Civil Work Construction Commencement
2010:	Feasibility Study – A World Wide Search of Air Purification System (APS) and its Applications
2011:	Incorporation of APS in the Commissioning Contract (CC)
2013:	Call for Tender - Contract No. HY/2011/08
	- for Tunnel Buildings, Systems and Fittings, and works associated with Tunnel Commissioning
2013:	Environmental Permit to Operate (Approved)
2014:	Award to Leighton Joint Venture (Contract Sum: HK$ 3,181.89 million)

AIR QUALITY REQUIREMENTS

Tunnel Air Quality Criteria:

Parameter	Maximum Concentration [1], [2]
CO	100ppm
NO_2	1ppm
SO_2	0.4ppm

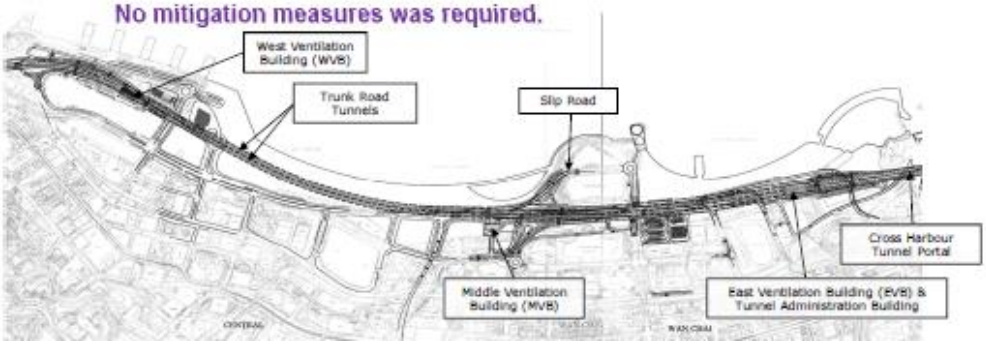
Notes:
(1) Averaging time is 5 minutes
(2) Measured at 298K and 101.325kPa

AIR QUALITY REQUIREMENTS

2001: Initial Environmental Impact Assessment

- Results show that the predicted air quality at the Air Sensitive Receivers (ASRs) would comply with the Air Quality Objectives (AQOs).

No mitigation measures was required.



AIR QUALITY REQUIREMENTS

2007: Final Environmental Impact Assessment – a further step of air quality enhancement

- With the Trunk Road tunnel ventilation system designed for zero portal emission at the eastern portal, at North Point, potential air quality impacts from the tunnel portal emission were to be avoided.
- The air quality at the eastern portal area would be enhanced by locating the vent shaft at the end of the eastern breakwater of the Causeway Bay Typhoon Shelter (CBTS) and by the introduction of an electrostatic precipitator system (ESP) at the East Ventilation Building (EVB) to screen RSPs from the tunnel emissions.

An ESP was identified at EVB

AIR QUALITY REQUIREMENTS

2007: Environmental Impact Assessment (Continued)

AIR QUALITY REQUIREMENTS

2009: Environmental Permit to Construct (Approved)

- An electrostatic precipitator(ESP) system shall be installed to reduce the dust emission from the EVB operation. The ESP system shall be designed to have a dust removal efficiency of 80% to reduce the level of respirable suspended particulates (RSPs).
- The ventilation system of the Eastern Portal of the CWB Tunnel shall follow the zero-portal-emission design approach.

AIR QUALITY REQUIREMENTS

2013: Environmental Permit to Operate (Approved)

- An Air Purification System (APS), including an electrostatic precipitator system (ESP), with removal efficiency of at least 80% of dust to reduce the level of respirable suspended particulates (RSPs), and a NO_2 removal system (De- NO_2 Filter) with removal efficiency of at least 80% for NO_2, shall be adopted to improve the air quality before discharging to the atmosphere via the WVB, MVB and EVB and its vent shaft.

APS is required at WVB, MVB and EVB

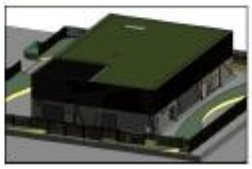
AIR QUALITY REQUIREMENTS

2013: Environmental Permit to Operate (Continued)

Design of Ventilation Buildings

	Air capacity (m^3/s)	velocity (m/s)	discharge height (meter above ground)	
West Ventilation Building (WVB)	420	8	15	Vertical

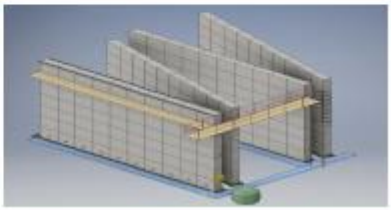
	Cross-sectional area of stack (m^2)	Exit velocity (m/s)	Minimum mid-discharge height (meter above ground)	Exhaust direction
Middle Ventilation Building (MVB)	210	8	17.5	Vertical
Vent shaft of the East Ventilation Building (EVB)	94	8	16.25	Inclined 45 degree upward (discharge towards sea direction)



AIR PURIFICATION SYSTEM

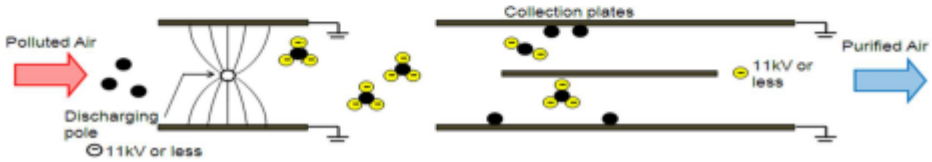
What is Air Purification System (APS)?

- CO, Dust, NOx (NO, NO_2, ….), …..
- Exhaust air will be treated by APS before discharging to ambient
- Two-stages treatment

Stage 1: Electrostatic Precipitator (ESP) To remove Respirable Suspended Particles (RSPs)	Stage 2: De-Nitrification (De-NO_2) Filter To remove NO_2
	

ELECTROSTATIC PRECIPITATOR (ESP)

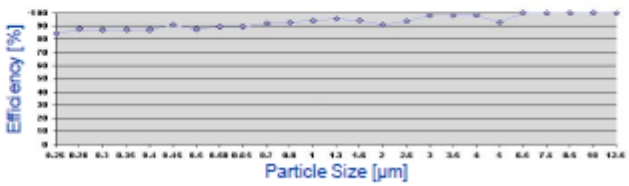
- To remove RSP from the exhaust air stream
- Minimum 80% efficiency in removing RSP is required
- Using electrostatic principles
  - Dust ionizing - electrically charged dust particles
  - Dust captured – by the Coulomb force in the electric field



ELECTROSTATIC PRECIPITATOR (ESP)

- A survey of aps product performance in market

	Supplier A	Supplier B	Supplier C	Supplier D	Supplier E
Efficiency	> 90%	80% ~ 95%	> 80%	> 80%	90-96%

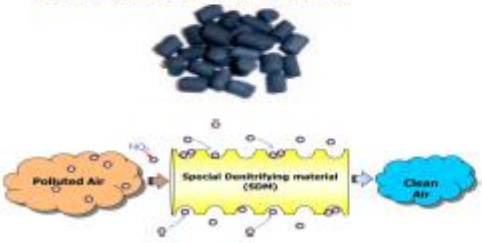


Efficiency relating to the particle size

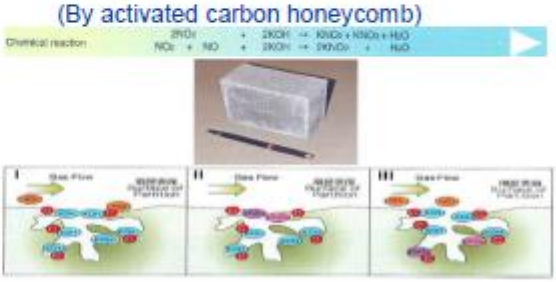
DE-NITRIFICATION (DE-NO_2) FILTER

- Mainly consists of Activated Carbon
- Minimum 80% efficiency in removing NO_2 is required
- Adsorption vs Absorption

- Adsorption
  (By activated carbon pellets)



- Absorption
  (By activated carbon honeycomb)



DE-NITRIFICATION (DE-NO_2) FILTER

- Technologies applied by APS suppliers

	Supplier A	Supplier B	Supplier C	Supplier D	Supplier E
Form of filters	Pellets	Pellets	Pellets	Honeycomb	Pellets
Adsorption or Absorption	Adsorption	Adsorption	Adsorption	**Absorption**	Adsorption
Regeneration Required	-	-	May required (In-situ)	May required (Outside)	-
Efficiency	> 80%	90%	> 90%	> 90%	85%

APS REGENERATION PLANT

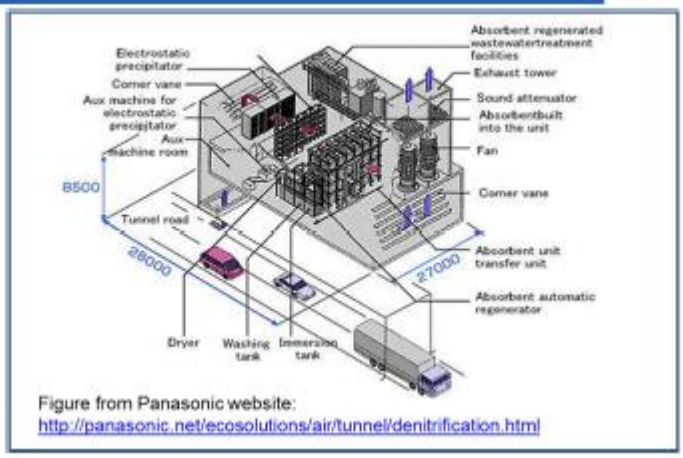
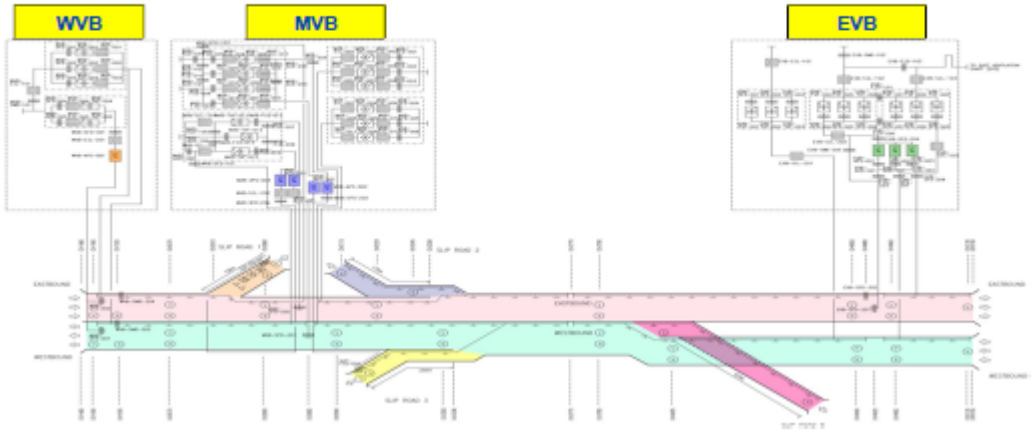


Figure from Panasonic website:
http://panasonic.net/ecosolutions/air/tunnel/denitrification.html

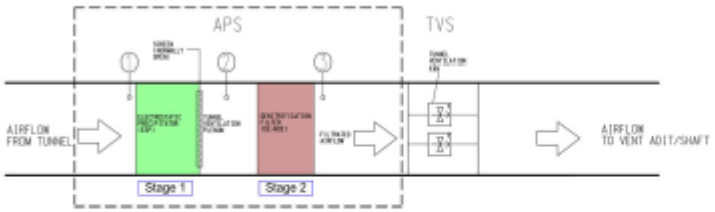
APS REGENERATION PLANT

	No Regeneration System	Regeneration Inside Ventilation Building	Regeneration Outside Ventilation Building
Regeneration Frequency	Not required	Frequent (e.g. every 2 weeks)	Less frequent (e.g. every 6 months)
Life Time of Activated Carbon	Base (e.g. 3 years)	Longer (e.g. 5 years)	Longest (e.g. 10 years)

TUNNEL VENTILATION SYSTEM & AIR PURIFICATION SYSTEM SCHEMATIC



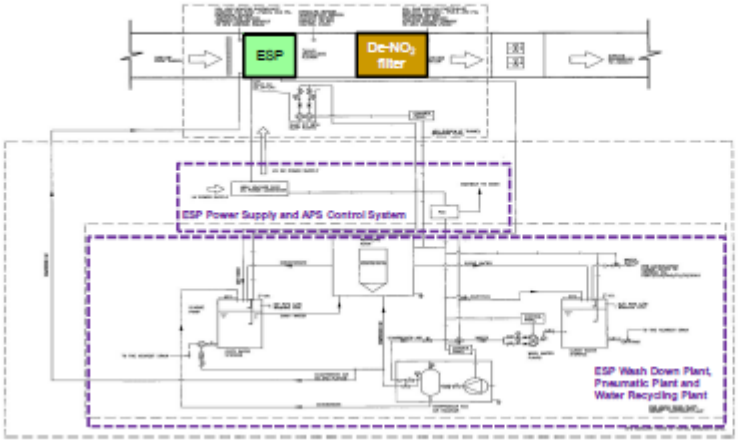
AIR PURIFICATION SYSTEM SCHEMATIC



Installed Sensor Type	①	②	③
Temperature sensor	✓	✓	✓
Humidity sensor	✓	✓	✓
Pressure Sensor	✓	✓	✓
Particulate monitor	✓		✓
NO_2 Gas monitor	✓		✓

Cases	Pollutant	Inlet - ①	Stage 1 - ②	Stage 2 - ③
High Conc. Condition	RSP (mg/m^3)	1.1 (max)	0.22 (max)	0.22 (max)
	NO_2 (ppm)	1 (max)	1 (max)	0.2 (max)
Very Low Conc. Condition	RSP (mg/m^3)	≤0.5 (e.g. 0.2)	≤0.1	≤0.1
	NO_2 (ppm)	≤0.25 (e.g. 0.1)	≤0.25	≤0.05

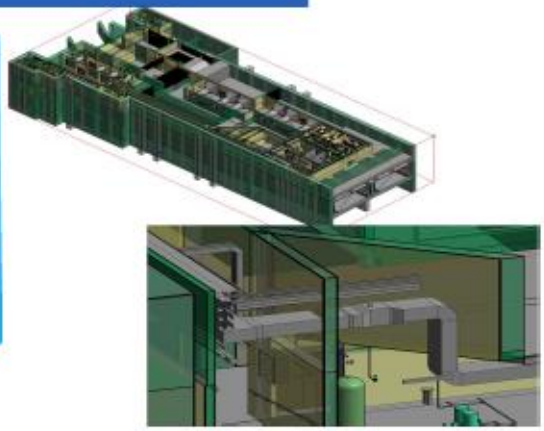
AIR PURIFICATION SYSTEM SCHEMATIC



- ESP
- De-NO_2 filter
- Associated Systems:
  - ESP Power Supply and APS Control System
  - ESP Wash Down Plant, Pneumatic Plant and Water Recycling Plant
- Discharge:
  - Waste Water
  - Dust Cake

PROJECT CHALLENGES

- Zero portal emission
- Operational cost
- External parties / public
- Spatial constraint
- Establish fire services provision
- High pressure drop across APS (First time use of two stage fan in HK)
- 1st APS plant in Hong Kong
- Installation of activated carbon

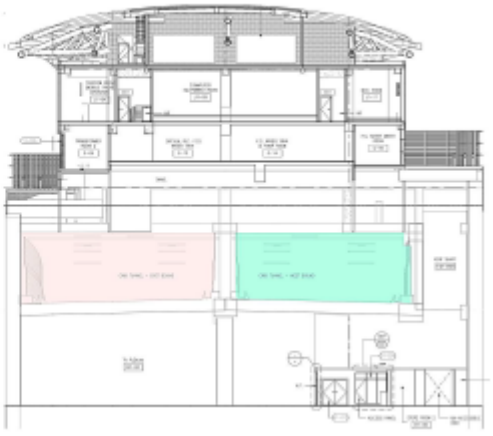


PROJECT CHALLENGES

- Spatial Constraint
  - Building area fixed by lot boundary

Solution:

- Plant rooms built below tunnel level
- Compact size plant room design for APS
- CFD application to improve air flow



PROJECT CHALLENGES

- **Establish Fire Services Provision**
  - Storage of activated carbon in underground plantroom

  Solution:
  - No ignition to airstream of 250°C for 15 minutes for activated carbon
  - Isolate APS during emergency operation
  - Storage of activated carbon in accordance with consumption needs (Just in Time concept)


Agreement No. CE 9/99

Central-Wan Chai Bypass and Island Eastern Corridor Link

Fire Emergency Operation of the Tunnel Ventilation System (Tunnel Ventilation with Air Purification System)
December 2011

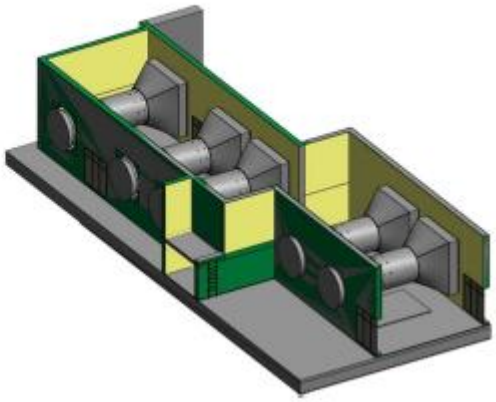
Submitted to: Fire Services Department, Hong Kong SAR

PARSONS BRINCKERHOFF

PROJECT CHALLENGES

- **High Pressure Drop Across APS**
  - 850Pa (ESP & De-NO_2) pressure drop across APS units

  Solution:
  - Installation of 2-stage fans to handle high pressure loss



PROJECT CHALLENGES

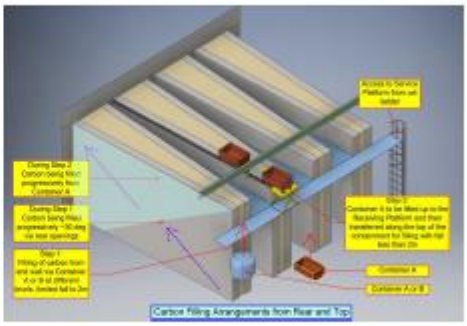
- **1st APS Plant in Hong Kong**
  - Need detailed evaluation of various APS performances before decision to use
  - Actual traffic environment in Hong Kong
  - Comprehensive Factory Acceptance Testing planned for APS
  - Inexperienced local maintenance contractor for APS

  Solution:
  - The contractor shall ensure necessary enhancement in APS maintenance through special training / technology transfer from the original APS supplier / overseas operators such that specified efficiency is achieved during the maintenance period

PROJECT CHALLENGES

- **Installation of Activated Carbon**
  - Construction Stage – Delivery of carbon closed to end of construction
  - Future Replacement – Life time of carbon

  Solution:
  - Construction Stage – Use of temporary service platform
  - Future Replacement – Regular test of activated carbon to predict the remaining life time
  - Future supply of activated carbon via selected sources of suppliers



OPERATION OF APS

- **Normal Operation**
  - Air exhausted from tunnel to be monitored regularly
  - All air discharged to the ambient via ventilation buildings will be treated by APS with min. 80% RSP & NO_2 removal efficiency

- **Fire Emergency Operation**
  - APS will be isolated from tunnel smoke control system during emergency by Motorised Fire and Smoke Dampers
  - Activated carbon: 250°C (no ignition)

MODIFICATION OF M&E SYSTEMS TO ENHANCE APS

- **Tunnel Ventilation System**
  - More powerful fans are required (850Pa pressure drop across APS)
  - More dampers to isolate APS and TVS

- **Other Mechanical & Electrical Systems**
  - Increased power supply for TVFs and APS
  - Additional water supply and drainage system for cleaning the APS
  - Additional building services for APS (e.g. air-conditioning for APS control room)
  - Additional sensors and interface with Central Control & Monitoring System (CCMS)

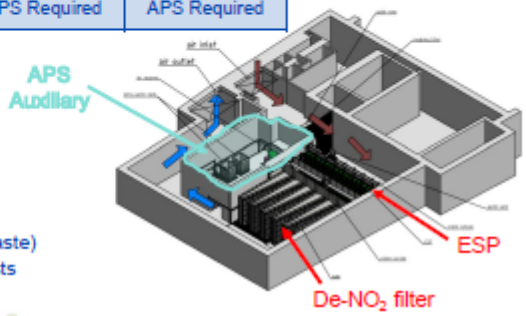
- **Others**
  - Additional space and ductwork for housing and delivery of the APS equipment
  - Additional sump pit
  - Additional lifting provision for delivery

CONCLUSION

- Experience in CWB

Requirements	WVB	MVB	EVB
2001	No migration measured required		
2007	No migration measured required		ESP Required
2013	APS Required	APS Required	APS Required

- Air Purification System
  - Type of APS (ESP, NO_2, NO_x)
  - Pressure drop, power, E&M provisions (e.g. use of 2-stage fans)
  - Spatial requirement
  - Safety
  - Fire Services Department concern
  - Waste (solid waste + waste water, chemical waste)
  - Initial cost + running cost → Total life cycle costs



CONCLUSION

Use of APS is one of the solutions.

Figure from paper:
Ventilating Central-Wan Chai Bypass:
Road Network Upgrade Paves the Way to Cleaner Air