IPL Programme: Innovatie dmv analyseren van patenten (Innovation Capture through Analysis of Patent Documents)

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Centre for Sustainability at TRL Limited

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Executive Summary

In the Netherlands, air quality is currently an urgent issue. The Netherlands is not complying with the new European standards for fine dust particulate matter (PM_{10}), and are unlikely to be able to comply with the future standards for nitrogen dioxide (NO_2).

The Air Quality Innovation Programme (IPL) was set up to help achieve compliance with these standards. IPL is run jointly by the Dutch Transport and Environmental ministries, and aims to develop site specific techniques to improve air quality at motorway 'hotspots'. By 2008, IPL is to compile a catalogue containing innovative measures to mitigate emissions and air quality impacts. The most effective measures developed will be incorporated into a National Programme of Measures by the Dutch government.

The aim of this review is to aid The Department of Road and Hydraulic Engineering (DWW) in identifying innovative solutions, from patent documents, to mitigate emissions and air quality impacts. Various patents covering a range of technologies of potential relevance to IPL were identified and provided to TRL by DWW. In total, 61 patent documents were then qualitatively reviewed and information recorded in accordance with the following review framework:

- Category – a grouping by the proposed application for the patented technology
- Patent registration date
- Has the patent been superseded?
- Have the patent fees been paid?
- Description of patent
- Which pollutants are being addressed?
- Maturity of technology
- Unit cost estimate (set up and maintenance/operation)
- Durability/life cycle
- Practicality
- Political appeal
- Public acceptability
- Potential for IPL implementation (High/Medium/Low)

Out of the 61 patents reviewed, 8 were classified as having high potential for IPL, 21 as medium, and 25 as low. Out of the remaining 7 patents, 2 could not be classified because they were unclear, and 5 were not fully reviewed as they were considered to be out of date and not relevant to the Dutch situation and IPL.

The eight patents classified as having the highest potential for further exploration and adoption in IPL utilise various combinations of six basic technologies. These are:

- filters, absorbents and adsorbents;
- bio-filtration;
- denitrification;
- electrostatic precipitation;
- systems providing heat and power; and
- photo-catalyst methods.

From the information reviewed, it is these six technologies appear to warrant the greatest attention and further development for IPL.

The selection of patents only really provides a "snapshot" of the development of various technologies and many of the technologies will have since been adopted, revised or abandoned. For this reason it is concluded that there is great potential to make further use of patents and other sources of information to develop potential applications for the technologies and move towards pilot studies. Also, it is important to note that these technologies (or patents) can and should be used in combination for maximum impact. "Hybrid" solutions adopting various technologies can, in many cases, be combined at a micro scale (individual sites). In any case, combinations are possible at a macro scale (road/corridor/area/region).

Based on this review and analysis of 61 patents, various recommendations have emerged. All of these recommendations are focused on the Dutch situation and aim to contribute to the IPL programme and are grouped in terms of: A) recommendations to exploit the identified technologies; B) recommendations for how patents and similar sources can be further utilised; and C) other recommendations.

A) Recommendations to exploit the identified technologies

A1. Undertake a combined "state of the art review and IPL feasibility study" for each of the six technology areas (filters and absorbents, bio-filtration, denitrification, electrostatic precipitation, photo-catalysts, and the production of heat and energy in combination with air purification).

A2. Undertake a combined "state of the art review and IPL feasibility study" for two other technologies: activated asphalt; and agglomeration techniques.

B) Recommendations for how patents and similar sources can be further utilised

B1. Adopt the results database as a live information source for the IPL. Use and develop it to capture and store information from other patents and technologies as they emerge from the various activities in the IPL programme.

B2. Undertake targeted searches of worldwide patents/patent databases to provide additional information on the evolution of the six technologies identified with the highest potential (links to recommendation A1).

B3. Develop and test different ways of searching and analysing the large "pool" of worldwide patents/patent databases to map the development and evolution of technologies of relevance to the IPL.

C) Other recommendations

C1. The IPL should continue to seek links with other national and international programmes and initiatives. These include consideration of the following:

- European Topic Centres
- National programmes
- European COST Actions
- European 6^{th} and 7^{th} framework programmes

C2. IPL should seek other mechanisms to review relevant activities on-going in Asia, Japan and North America.

1 INTRODUCTION

1.1 Background

Since the 1970s, air pollution has been one of Europe's main political concerns, and has led to the development of a tranche of European Union policy on air quality. The focus of this policy has been to improve the knowledge database on the relationship between emissions and air pollution, and ultmately to develop and implement appropriate instruments to improve air quality. It is evident that road transport represents a significant source of many pollutants. In general road transport emissions peaked during the early 1990s, and have subsequently declined, due to various measures to restrict emissions from individual sources or activities. However, road transport remains the dominant source of carbon monoxide (CO), oxides of nitrogen (NO_X)[1], particulate matter (PM_{10})[2] and some VOC species. Therefore European and national policies continue to seek the control of emissions from mobile sources, the improvement in fuel quality and the promotion and integration of environmental protection requirements into the transport and energy sector.

European legislation is in place, and under continual review, restricting emissions from all of the major UNECE[3] source categories. With respect to the control of emissions from road transport, the approach is two-fold whereby limits are set on the allowable emissions from the exhaust of individual vehicle types, supported by the introduction of regulations on the formulation and quality of road fuels. The adopted methodologies for compliance with this legislation has itself been two-fold, with the development of improved engine technology (modifications to the engine map), and exhaust after-treatment systems (including three-way catalysts, oxidation catalysts, exhaust gas recirculation, selective catalytic reduction, de-NO_X traps, diesel particulate filters and regenerative traps *etc*). All of these technologies have varying levels of control on the emission of specific pollutants, and thus the introduction of these types of technologies into the vehicle fleet, can have positive and negative[4] effects on specific emissions. The Netherlands has been a leader in the promotion of alternative road transport fuels, particularly liquid petroleum gas (LPG). The use of LPG during the 1990s had significant emission benefits over conventional fuels, and was thus subject to fiscal incentives. These emission benefits have now been reduced due to the gradual improvement in the emissions associated with conventional fuel technologies.

The concentration of a pollutant at a roadside receptor will be dependent on the magnitude of the source, and the distance between the source and the receptor. In practice, this simple relationship is complicated by the presence of multiple sources, contributions from background concentrations, the role of atmospheric chemistry in the formation and transformation of pollutant species (particularly important for NO_2 and the secondary component of particulate matter), and the over-ridding influence of meteorology. Therefore the improvement in roadside air quality, is not restricted to the control of transport emissions, but also the control of other source categories, regional policies on the reduction in ground level ozone and the introduction of mitigation regimes that reduce roadside exposure at sensitive locations.

[1] NO_X is the conventional term for the sum of nitric oxide (NO) and nitrogen dioxide (NO_2). Vehicle exhaust emissions are dominated by NO, with the proportion of NO_2 ranging from less than 5% to over 40% (the latter relating to the use of specific exhaust after-treatment systems).

[2] PM_{10} refers to those particles with an aerodynamic diameter of less than 10 microns.

[3] United Nations Economic Commission for Europe.

[4] For example, recent evidence has indicated that various exhaust after-treatment systems are associated with an increase in the emission of primary NO_2, as a proportion of total NO_X.

In common with other European Union member states, air quality in the Netherlands, remains a topical issue. The year 2005 was a significant year for European air quality, as it was the first year for compliance against the European Directive on particulate matter. This set annual and 24-hour mean limits on PM_{10} concentrations. Preliminary data suggests that the Netherlands will be in breach of this Directive, and that it is unlikely to be able to comply at all locations with the future standards for NO_2, to be introduced in 2010. As a result, a series of development schemes have been put on hold, and the European Union has informed the Netherlands that they must use maximum reasonable effort to rectify this situation. The Ministry of Housing, Spatial Planning and the Environment (VROM), and the Ministry of Transport, Public Works and Water Management (DWW) are thus actively involved in the investigation and piloting various initiatives aimed at improving this situation. More information on Dutch air quality standards and recent data are available via the Environmental Data Compendium[5].

In response to this, the Dutch Air Quality Innovation Programme (IPL) was established up by VROM and DWW with the aim of developing innovative strategies to help achieve compliance with these standards. The main focus for IPL is on a number of routes through densely populated areas that currently qualify as pollution 'hotspots'. At these sites, IPL measures will be put in place to help improve the situation in terms of NO_2 and $PM_{10.}$

Following a preliminary research phase, commencing in the spring of 2005, the IPL team and its collaborators have instigated investigations into a range measures including:

- The catalytic breakdown of NO_X along motorways'. Can a photocatalytic layer of titanium dioxide (TiO_2) be deployed effectively on noise barriers, for example, to reduce NO_X concentrations along busy motorways?

- The effect on air quality of optimized noise barriers'. How can (existing) noise barriers be adapted or designed in such a way that they contribute to the reduction in downwind pollution concentrations through the restriction or diversion of airflows?

- The effect on air quality of lightweight coverings over motorways'. Is it (economically) feasible to enclose sections of busy motorways, purify the air within the resulting 'tunnel' and thus contribute to cleaner air in the immediate surroundings of the road?

- The effect on air quality of vegetation along motorways'. To which extent and in which way can vegetation contribute to improved air quality on and along motorways?

- The effect on air quality when motorways surfaces are cleansed. To which extent can wet-spraying or wet-brushing roads prevent or reduce the resuspension of particulate matter[6], and its contribution to roadside air quality?

- The effect of dynamic traffic management based on air quality forecasts'. Can temporary traffic measures be put into effect at moments that an air quality forecast requires it? Which measurements and forecasts would that then

[5] see: http://www.mnp.nl/mnc/i-en-0237.html
[6] The resuspension faction is taken as the size fraction between PM_{10} and $PM_{2.5}$.

involve? And which measures: 80 kph, compliance with certain Euros classes, closing lanes, etc.

These projects are supported by on-going desk-top research, explorations into emerging technologies via a review of patents, investigations into international best-practice, and through participation in meetings and conferences with specific experts, local governments, the business sector, and the wider stakeholder community.

By 2008, IPL is aiming to compile a catalogue, based upon the results of these various initiatives, which will summarise measures with the ability to improve roadside air quality. The most effective of these measures will be incorporated into a National Programme of Measures by the Dutch government.

The Department of Road and Hydraulic Engineering (DWW) commissioned TRL to assist in this process, with the task of identifying suitable technologies for IPL by examining a range of patents which propose an assortment of concepts and technologies. 61 patents were pre-selected by DWW and provided to TRL. From that starting point, TRL's analysis of the patents has included an examination of their technical and economic feasibility for improving air quality, and their potential public and political appeal within the Netherlands.

1.2 Report Structure

This report is divided into six sections:

- Introduction;
- The aims and objectives of the project;
- The methodology used to review the patents;
- The results of the review;
- A discussion of the results; and
- Conclusions and recommendations.

2 AIMS AND OBJECTIVES

The overall aim of this project was to capture innovations through the analysis of 61 patent documents relating to the mitigation of emissions and air quality impacts. In achieving this aim, DWW will have a greater understanding of the technologies being developed, or that have been developed, to mitigate emissions and air quality impacts. By examining international patented inventions, the project will provide "signposts" to where research and technological developments are underway and identify those individuals and institutions involved in these developments.

This project, therefore, will potentially help DWW to identify options for consideration for compliance with the European air quality limit values for PM_{10}, the proposed draft standards for fine particulate matter ($PM_{2.5}$) currently subject to discussion under the umbrella of the EU Thematic Strategy on air pollution, and the existing future European standards for NO_2.

This proposed research can be broken down into four key objectives:

- To obtain the 61 patent documents provided by DWW, and translate them where necessary;
- To analyse the 61 patent documents;
- To extract from these patents, those innovations that may be suitable for use by DWW for the mitigation of emissions and air quality impacts; and
- To make recommendations for further research and development of the most promising innovations.

3 METHODOLOGY

3.1 Development of a review framework and results database

The basis of this project was to conduct a qualitative review of patents using expert judgment. The patents of potential relevance to IPL were identified and provided to TRL by DWW. A review framework and a results database were created in order to ensure that the patents were analysed and the results recorded in a systematic way. The starting point for the review framework was provided by a set of overarching criteria for IPL measures previously discussed with DWW, in February 2006 (see Table 1). The specific patent review framework was then development in light of these criteria and the nature of the information available within the patent documents.

Table 1: General criteria for the review and analysis of measures in IPL (as discussed between TRL and DWW in February 2006).

Primary	• Environmental effects are quantified.
	• Time horizons (lead in time to implementation) are identified:
	  o <3 years;
	  o 3 – 6 years.
	• Key factors for implementation are identified:
	  o Success/failure;
	  o Focus – *e.g.* technological push, marketing push, fiscal measures needed.
	• Practical options for piloting are identified.

Secondary	• Relevance to IPL. • Focus the reviews outside the Netherlands. • First results available in 2006. • Cost effectiveness including durability/life cycle value. • Practicality. • Political appeal. • Public acceptability.

Box 1 displays the adopted patent review framework. The results were captured in a database using Microsoft Excel and later translated into Microsoft Access[7].

Box 2: Patent review framework.

1. Category – a grouping by the proposed application for the patented technology *
2. Patent registration date
3. Has the patent been superseded?
4. Have the patent fees been paid?
5. Description of patent
6. Which pollutants are being addressed?
7. Maturity of technology
8. Unit cost estimate – capital
9. Unit cost estimate – maintenance/operation*
10. Durability/life cycle
11. Practicality
12. Political appeal
13. Public acceptability
14. Potential for IPL implementation (High/Medium/Low)

* these fields were not included initially but were added to the review framework to provide additional information.

[7] please see the attached CD-Rom for the Microsoft Access database.

3.2 Pilot of the review framework and database

Four of the most recent patents, representing a range of innovations, were selected and reviewed as a mini "pilot study" (see Table 2). This limited pilot provided an opportunity to test the assessment framework and database. Following this review, an additional category was added to the database; "Unit cost estimate (Maintenance and Operation)". This was because it was felt that the balance between the capital costs associated with the technology set-up could be quite different to the ongoing maintenance and operational costs.

Table 2: Patents reviewed as part of the pilot study.

Name of Applicant	Title of Patent	Registration Date
Josip Pavetic	Process for the ventilation of road tunnel	2000
Dennis T Griggs	Covered highway structure with means for easy and quick access to tunnel interior	2003
Phillip A Lincoln	Air treatment method and apparatus for reduction of VOCS NO_X and CO in an air stream	1999
Hyder Consulting PTY Ltd	Tunnel exhaust air treatment	2004

3.3 Patent analysis

Following the pilot phase, the remaining 57 patents were reviewed. This analysis was initially undertaken by examining individual patents. Due to the difficulty in obtaining English versions of the full patent documents from the patent database sources, where full English abstracts existed these were utilised and the remaining patent documents translated. The complete list of the patents reviewed is provided in Annex A.

Once all of the patents had been reviewed, panel discussions were held to cross check patents and technology areas and to discuss their relevance to the Dutch situation generally and the IPL specifically. These discussions helped to reduce the subjectivity of the initial review. At this stage, the patents were also categorised in terms of the type of application described for the patent (e.g. a ventilation system for tunnels) – see section 4 for more details.

3.4 Project outputs

Two outputs have been produced as part of this project:

- An electronic copy of the results database in MS Access format;
- A short report (this report) summarising the results of the review and drawing out conclusions and recommendations regarding the relevance of the findings to the IPL.

4 RESULTS

The full results of the review and analysis are provided in Annex A. A comprehensive analysis was undertaken with most of the aspects of the review framework completed for most of the patents. Some review aspects of some of the patents was omitted due to the paucity of information available from within the patent registry.

During the review, it became clear that the patents could be grouped in different ways. In particular, the patented technologies have particular proposed applications such as proposed uses associated with tunnels. The following categories were established and each of the patents was assigned to one of them to aid the analysis:

- Patents using ventilation changes to tunnels. These reduce pollutant concentrations in the tunnel but not necessarily at the ventilation exhaust and within the local environment (category 1).
- Patents using air treatment processes of the exhaust ventilation air. These reduce pollutant concentrations near to the ventilation exhaust and the local environment, but not necessarily within the tunnel confines (category 2).
- Patents using a combination of ventilation and air treatment. These could reduce pollution both inside and outside the tunnel (category 3).
- Patents using methods of reducing air pollution unrelated to tunnels (category 4).
- Patents not primarily involved with air pollution control, for example, fire and noise suppression (category 5).

Of the 61 patents reviewed, 8 were classified as having a relatively high potential for the Dutch situation and IPL (see

Table 3). Of the remaining, 21 were classified as of medium potential for IPL and 25 classed as offering a low potential. Out of the remaining 7 patents, 2 could not be classified because insufficient details were provided within the patent, and 5 were not fully reviewed as they were considered to be superseded by more recent technologies and were thus not relevant to IPL and the Dutch situation.

Table 3: Patents classified as having high potential for IPL.

Name of Applicant	Title of Patent	Description of Patent (extracted from the patent description)	Regis-tration Date
Fuji Electric Co Ltd	Ventilating device for motorway tunnel	This ventilation system comprises a system to eliminate dusts and oxides of nitrogen from air in motorway tunnels. The system consists of an electrified dust collector and a noxious gas eliminating device (containing a reaction tube consisting of glass with TiO_2 powder, active carbon powder, and Fe_2O_3 powder with a light source in 300-400nm wavelength). The noxious gases are intended to adhere to the reaction tube. The dust collector and noxious gas eliminator are connected to the tunnel via a suction port and a discharge port.	1991

Name of Applicant	Title of Patent	Description of Patent (extracted from the patent description)	Regis-tration Date
Fujita Corp	Cleaning method of polluted air in tunnel	Tunnel air is passed into an upper cavity situated along the length of the tunnel roof. This air is forced through a soil profile and back into the tunnel cavity. (this presumably consumes converts or otherwise removes some of the pollutants through biological action, although this isn't stated).	2000
Emil Johannes Wieser-Linhart	Construction built along a road for noise and fumes reduction	This system involves building a tunnel (consists of a roof and walls held together by release mountings) over the road surface to reduce noise and to restrict the dispersion of air pollutants. The road cover includes an exhaust gas extractor attached to a cleaning unit. The cleaning unit incorporates air filters for solids and a biological cleaning stage for CO, NO_x and a range of hydrocarbons. In addition the roof has acoustic dampers at its base to help to absorb the road noise.	2003
Hyder Consulting PTY Ltd	Tunnel exhaust air treatment	Tunnel exhaust air treatment: method for reducing pollutants in a road-tunnel exhaust stack by passing the polluted air through a filter and gas turbine or combustion chamber/and a selective catalytic reduction (SCR) catalyst before exhausting to atmosphere.	2004
Anders Krantz	Method & installation for air treatment in the area of a traffic route for motor vehicles	An air quality improvement system involving the encapsulation of heavily trafficked roads/interchanges in a shell like structure. The exhaust air from vehicles is extracted through an outlet at a low level (allowing for the entrainment of gases and their constituents *e.g.* sulphur dioxide, carbon dioxide, nitric oxide, nitrogen dioxide and lead) and passed to air treatment stations. In an air treatment station the air is passed through 2 sets of filters (filter tubes may contain different types of absorbents such as active carbon or molecular sieve, PURAFIL etc). The filtered air is then vented to the atmosphere. Fresh air enters the shell through lower and upper inlets to create air currents, which can be controlled through the use of dampers.	1990
Atsushi Katatani	Denitrification system	A denitrification system comprising an electrostatic precipitator, an ozonizer, and ozone supply nozzle, a fan, a humidifier, a humidity sensor, and a NO_2 absorbent filter. The exhaust gases are passed first through the electrostatic precipitator to remove particulate matter, then mixed with the ozone produced by the ozonizer in order to convert NO to NO_2 and finally through the NO_2 absorbent filter. The humidifier and humidity sensor allow for humidity to be kept at the optimum level for the denitrification process.	1994

Name of Applicant	Title of Patent	Description of Patent (extracted from the patent description)	Regis-tration Date
		This system helps to overcome many of the issues associated with conventional denitrification systems *e.g.* soot and dust build up on the filter and humidity variance.	
Fujita Corp	Cleaning of polluted air in tunnel	A system to clean polluted air in tunnels by extracting the air from the tunnel and allowing it to pass through a layer of soil before allowing it to vent to the atmosphere.	
Ursula Lutzkat	Light-permeable noise and environmental protection cover for motor ways etc. consists of tunnels of recycled waste materials, with solar collectors, exhaust filters, etc.	This system involves covering a road in a tunnel type structure that is transparent, sound absorbent and made from recycled materials. The cover has solar collectors and integral filter systems for exhaust fumes. This system can be coupled to energy generating biological waste recycling plants to generate energy, heat or fertiliser – although the details of this aspect of the system would require further investigation. In addition, the tunnel cover can be covered by a bridge for cyclists, pedestrians and animals.	1998

The eight patents with the highest potential are based on various technologies (e.g. denitrification and biological cleaning systems) and these are discussed further in section 5.

5 DISCUSSION

The eight patents classified as having the highest potential for further exploration (

Table 3) utilise six different technologies. These are:

- filters, absorbents and adsorbents;
- bio-filtration;
- denitrification;
- electrostatic precipitation;
- systems linked with heat and power generation; and
- photo-catalytic methods.

Whilst some of the individual patents may warrant some further consideration, it is also useful to consider the technologies that they adopt in a wider context. This is because the selected patents are essentially only a snapshot of the state of development of the technologies and may have been or about to be superseded by other developments – whether these developments are patented or not.

Each of the six identified technologies is discussed below in further detail. For each technology, the current state-of-the-art is briefly summarised.

5.1 Filters, absorbents and adsorbents

Filters, absorbents and adsorbents are used across the world in order to purify fluid streams, both gaseous and liquid. Filters operate by removing airborne particulate matter through the use of a physical barrier. A filtration system can be used to clean polluted air in tunnel ventilation stacks, in the tunnel itself, and at tunnel portals. In-tunnel systems rely on the iterative treatment of ambient air in the tunnel, and the subsequent introduction of the purified air back into the tunnel itself (Boulter *et al.*, 2006). However, particulate filtration efficiencies can be poor, of the order of 20% (Boulter *et al.*, 2006). The physical and chemical composition of the filter matrix can vary depending on the particle size range intended for collection, and the chemical composition and humidity of the source.

An example of a filtration system is that manufactured by Matsushita. This system is comprised of a multi-layered bed of filters which are incorporated into the dust collector (Matsushita ecology systems Co. Ltd, 2006). The dust collector is equipped with an automatic transport mechanism which transfers the filter units to a regeneration section when a filter becomes polluted and clogged with particulate matter. In this regeneration section, air blows across the filter to back-flush and remove the deposited particulate matter (Matsushita ecology systems Co. Ltd, 2006). In this kind of technology, the details of the removal and disposal measures would require further investigation.

Chemical absorbents/adsorbents can be used in conjunction with filters, or by themselves. They comprise of materials with high surface areas that absorb/adsorb pollutant species (Child & Associates, 2004) (see 5.3 for further details).

There are a number of specific substances that can be used for reducing pollutant concentrations within air stream. These substances include:

- **Activated carbon:** This adsorbent primarily removes larger hydrocarbons and many chemically active gases and vapours. It does not remove carbon

monoxide, methane, ethane, or propane. Some gases, such as arsine, will be absorbed but may desorb later under different conditions.

- **Purafil^{TM}:** This is comprised of potassium permanganate deposited on alumina pellets. It removes many reactive gases, including nitrogen dioxide, arsine and hydrogen sulphide, but not carbon monoxide. It also removes unsaturated hydrocarbons such as ethylene.

- **Hopcolite:** This is routinely used for removing carbon monoxide. Hopcolite consists of manganese dioxide and copper oxide. It can be deactivated by water or moisture in the air, as this reduces its catalytic activity.

- **Iron oxide - based catalysts:** These can remove hydrogen sulphide and are frequently used in the desulphurization of natural gas, naphtha, off-gas, and light hydrocarbons.

Filters, absorbents and adsorbents can be applied to a number of different situations, for example, Emil Johannes Wieser - Linhart (2003) in the patent titled "Construction built along a road for noise and fumes reduction" describes the use of filters in a cleaning unit on the roof of a shell like structure, purposely built over the road to reduce air pollution and to remove particulate matter from polluted air. Fuji Electric Co. Ltd (1991) in the patent titled "Ventilating device for motorway tunnel" describes the use of absorbents in reaction tubes. The reaction tubes are comprised of glass, and contain titanium oxide (see section 5.6), iron oxide and activated carbon.

It is important to note that filters, absorbents and adsorbents require regular replacement or regeneration, and may thus be a potential source of pollution during this phase. The disposal of contaminated absorbents, for example, may have to be treated as hazardous waste, and thus subject to additional costs.

5.2 Bio-filtration

Bio-filtration describes "processes in which contaminated air is passed over or through some medium containing micro-organisms capable of consuming, converting or otherwise removing some or all of the harmful pollutants present" (Child and Associates, 2004). Bio-filtration systems need to have relatively long exposure or residence times for the biological processes to be effective. Ambient air treatment, however, requires the treatment of large volumes of air relatively quickly, especially in road tunnel applications. Bio-filtration processes, therefore, offer substantial potential but design challenges remain.

In one bio-filtration system manufactured by Fujita, polluted air is passed through an aeration layer into one or two soil beds, each 50 cm thick. Removal efficiencies are stated as 95% for total suspended particulates (TSP), 91% for nitrogen dioxide, 88% for nitrogen oxide, 95% for carbon monoxide and 94% for sulphur dioxide (Child & Associates, 2004). As can be seen by these removal efficiencies, bio-filtration has a high potential for purifying polluted air.

Two of the patents reviewed used bio-filtration through soil profiles; Fujita Corporation (1999) "Cleaning method of polluted air in tunnel" and Fujita Corporation (2000) "Cleaning of polluted air in tunnel". One of the patents uses a bed of soil within the tunnel in order to clean the air in the tunnel. The other employs the soil profile above the roof of the tunnel and directs tunnel air through this layer, and eventually vents to the atmosphere.

5.3 Denitrification

Denitrification processes use either chemical adsorption or a catalytic process to accelerate the conversion of nitrogen oxides to less harmful or benign gases. Some of these systems also have the capacity to remove hydrocarbon compounds. The adsorbents have to be regenerated and catalysts may require an electrostatic precipitator (ESP) upstream of the denitrification system to remove particulate impurities that would otherwise coat the surface of and thus reduce the efficiency of the catalyst (Willoughby *et al.*, 2004). Typical removal efficiencies are between 85-90% for nitrogen dioxide, 30% for nitrogen oxide, between 60-75% for hydrocarbons and 80% for TSP (Child & Associates, 2004).

Denitrification in road tunnels has not been widely used, and as of 2004 the Laerdal Tunnel, Norway, was the only example of the operational use of denitrification (Child & Associates, 2004). This system consists of a nitrogen dioxide removal process. It is coupled with an ESP for pre-treatment to remove the particulate matter and increase the efficiency of the nitrogen dioxide removal process. It has been difficult to assess how well this system works due to low pollutant concentrations in the tunnel (Child & Associates, 2004). If DWW were to consider denitrification, further investigation into the levels of pollutants required for this process to be effective would be necessary.

Other systems such as those manufactured by Matsushita, Kawasaki and FILTRONtec have been tested and have proved to be very successful (Child & Associates, 2004).

The patent by Atsushi Katatani (1994) describes a denitrification system comprising of an ESP, a nitrogen dioxide absorbent filter, a humidifier and humidity sensor. The aim of the humidifier and humidity filter is to allow an optimum humidity level, for denitrification, to be maintained.

5.4 Electrostatic precipitation

An effective method of removing particulates from a gas stream is by the use of an electrostatic precipitator (ESP). ESP systems pass the contaminated air past electrodes. Electrons are released which attach to the dust particles to give them a net negative charge. The air is then passed through a passageway containing electrodes arranged in a series of parallel plates. The plates serve as grounded electrodes which attract the charged particles (Child & Associates, 2004).

There are two types of ESPs: dry and wet. ‘Dry’ electrostatic precipitators have collecting plates which are periodically shaken in order to dislodge the collected dust. “Dry” ESPs are effective in removing particles between 1 and 10 microns in diameter. They have claimed removal efficiencies of between 66 % (PM_1) and 98% (PM_{10}) (Child and Associates, 2004). ‘Wet’ ESP systems use a water flushing system to remove the particles from the collecting surface rather than a mechanical shaking process (Child and Associates, 2004).

“Dry” ESPs have been used widely in industrial applications, such as chimney stacks, but are not widely used in applications such as road tunnels. Wet” ESPs are a relatively new concept, and as of 2004 had also not been used in road tunnels (Child and Associates, 2004). However, the World Road Association (PIARC) and several ESP manufacturers have undertaken pilot tests of equipment efficiencies in a range of road tunnels. “

Two of the patents described as having high potential for IPL utilise electrostatic precipitators to remove particulate matter; Atsushi Katatani (1994) and Fuji Electric Co Ltd (1991). It is important to note that if IPL were to utilise ESPs, careful consideration must be given to the additional energy demands from these systems, and the required disposal strategies for the collected particulate matter.

5.5 Systems providing heat and power

Two of the patents classified as having high potential for IPL, both purify air and can be used to produce heat and energy.

Ursula Lutzkat (1998) describes a system of air purification that can be coupled to an energy generating biological waste recycling plant.

Hyder Consulting (2004) outlines a system where polluted air is first passed through a filter, and then used for combustion with a fuel such as natural gas in either a turbine or combustion chamber. The heat of combustion provides the temperature in the exhaust stream so it can be passed over a selective catalytic reduction (SCR) catalyst to remove any NOx produced from the combustion process in addition to the NOx contained in the original airstream. However, it may only be necessary to use part of the tunnel air in the combustor. The remaining air can be bypassed and then mixed with the exhaust gas before passing the entire mixture through the SCR catalyst. The amount of air which is bypassed will determine the temperature of this stream which must be high enough to ensure that the catalyst reduces the NOx.

Using a turbine in this way produces a local source of heat and power independently of the gas purification process. This approach can therefore offset energy production elsewhere so that the technology does not require an overall energy input. The benefits would depend on the relative economic and environmental benefits of centrally produced electricity and as well as the local requirements for energy. However, using a combustor without utilising the energy in some way would probably not be worthwhile for economic and environmental reasons.

5.6 Photo-catalytic methods

Photo-catalysts use ultra-violet (UV) light energy to induce the formation of strong oxidizing reagents which decompose some organic and inorganic substances in the atmosphere by oxidation. Photo-catalysis, therefore, accelerates oxidation processes and promotes faster decomposition of pollutants. Photo-catalysts can be applied to various construction materials such as glass, ceramics and cement binders. One of the most commonly used photo-catalysts is the compound TiO_2. Coatings containing TiO_2 are effective because air turbulence constantly carries NO_x and other volatile and semi-volatile compounds over surfaces that could be readily treated with a layer of TiO_2 (Boulter *et al.*, 2006). The molecules stick to the surface long enough for the oxidation process to break them down. The acidic products created by this process can be washed away by rain, removed with water jets and/or neutralized by alkaline compounds (*e.g.* calcium carbonate) that can be mixed with the TiO_2 (Boulter *et al*., 2006). The use of TiO_2 can also prevent buildings and windows from being stained and damaged by urban pollution (Boulter *et al*., 2006).

Field trials conducted in Milan on a coated-road surface in 2002 on 7000 square metres of road surface which were covered with a photo-catalytic impregnated cement-like material showed up to a 60% reduction in the concentration of NO_2 at street level (Child & Associates, 2004). Other studies with titanium dioxide/activated carbon/iron oxide catalysts show nitric oxide (NO) removal ranging from 33% to 89%

(Pacific Northwest Pollution Prevention Resource Centre, 1999). Research on this topic is also ongoing through the European funded Photocatalytic Innovative Coverings Applications for Depollution Assessment programme (PICADA[8]).

The patent described by Fuji Electric Co. Ltd (1999) uses reaction tubes containing titanium oxide, iron oxide, activated carbon and UV light to purify polluted air in tunnels.

5.7 Technologies relevant to IPL but not mentioned in the patents reviewed

There are a number of other technologies that may be relevant to IPL but have not been included within the reviewed patents. These include technologies that could be built into the road infrastructure and street furniture, and include the following:

- Activated asphalt: This can be used to remove particulate matter from ambient air, and can help to reduce particulate soiling on tunnel walls and other street furniture.
- Agglomeration techniques: This technique can be used as a pre-treatment method within particulate removal systems. It works by promoting the formation of larger particles, through the agglomeration of smaller particles.

In addition, there are other kinds of techniques and technologies that would directly or indirectly affect emissions and air quality including:

- Active traffic management: Flow responsive traffic management, aimed at optimising fuel consumption and reduce vehicle emissions. This would include strategies such as variable speed limits, ramp metering and dedicated lanes.
- Reduced or increased speed limits and associated enforcement.
- Improvement in lane discipline, with the aim of reducing lane changes and smoothing traffic flow.
- Low emission zones: Geographic zones that exclude certain types of vehicles from air pollution “hotspots”.
- Road pricing by emission standards. Variable road charges dependant on the relative emission performance of the vehicle or operational mode.
- Identification of high polluting vehicles using vehicle exhaust remote sensing systems, and links with fault rectification regimes.

[8] See: www.picada-project.com

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The eight patents with highest potential for IPL identified in this review utilise various combinations of six basic technologies (filters and absorbents, bio-filtration, denitrification, electrostatic precipitation, photo-catalysts, and the production of heat and energy in combination with air purification). From the information reviewed, it is these six technologies that appear to warrant the greatest attention and further development for IPL.

The selection of patents only really provides a "snapshot" of the development of various technologies and many of the technologies will have since been adopted, revised or abandoned. For this reason it is concluded that there is great potential to make further use of patents and other sources of information to develop potential applications for the technologies and the move towards full scale trails.

Finally it is important to note that these technologies (or patents) can and should be used in combination for maximum impact. "Hybrid" solutions adopting various technologies can, in many cases, be combined at a micro scale (individual sites). In any case, combinations are possible at a macro scale (road/corridor/area/region).

6.2 Recommendations

Based on this review and analysis of 61 patents, various recommendations have emerged. All of these recommendations aim to contribute to the goals of the IPL programme and are grouped in terms of: A) recommendations to exploit the identified technologies; B) recommendations for how patents and similar sources can be further utilised; and C) other recommendations.

A) Recommendations to exploit the identified technologies

A1. Undertake a combined "state of the art review and IPL feasibility study" for each of the six technology areas (filters and absorbents, bio-filtration, denitrification, electrostatic precipitation, photo-catalysts, and the production of heat and energy in combination with air purification).

A2. Undertake a combined "state of the art review and IPL feasibility study" for two other technologies: activated asphalt; and agglomeration techniques.

B) Recommendations for how patents and similar sources can be further utilised

B1. Adopt the results database as a live information source for the IPL. Use and develop it to capture and store information from other patents and technologies as they emerge from the various activities in the IPL programme.

B2. Undertake targeted searches of worldwide patents/patent databases to provide additional information on the evolution of the six technologies identified with the highest potential (links to recommendation A1).

B3. Develop and test different ways of searching and analysing the large “pool” of worldwide patents/patent databases to map the development and evolution of technologies of relevance to the IPL.

C) Other recommendations

C1. The IPL should continue to seek links with other national and international programmes and initiatives. These include consideration of the following:

- European Topic Centres
- National programmes
- European COST Actions
- European 6th and 7th framework programmes

C2. IPL should seek other mechanisms to review relevant activities on-going in Asia, Japan and North America.

7 REFERENCES

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Willoughby, P., Stricker, J. and Humphrey, G. (2004). Electrostatic precipitators and ventilation in road tunnels in Japan. Report of a visit by a delegation from the NSW Roads and Traffic Authority to Japan from 30 September – 10 October 2003. New South Wales Roads and Traffic Authority, February.

ANNEX A: RESULTS SHEETS FOR THE PATENTS (EXTRACT FROM THE PATENT REVIEW DATABASE)

Key to the “Category” field within the results sheet:

- Patents using ventilation changes to tunnels. These reduce pollutant concentrations in the tunnel but not necessarily at the ventilation exhaust and within the local environment (category 1).
- Patents using air treatment processes of the exhaust ventilation air. These reduce pollutant concentrations near to the ventilation exhaust and the local environment, but not necessarily within the tunnel confines (category 2).
- Patents using a combination of ventilation and air treatment. These could reduce pollution both inside and outside the tunnel (category 3).
- Patents using methods of reducing air pollution unrelated to tunnels (category 4).
- Patents not primarily involved with air pollution control, for example, fire and noise suppression (category 5).

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
1	Robert S Blair	

Title of Patent

Art of and apparatus for ventilation

Country	Language	Date	Superseeded	Fees Paid? Y/N
USA	English	1929	N	N

Description of patent

Air is supplied to the tunnel via a lower parallel duct from both ends of the tunnel and is removed in an upper parallel duct exiting at both ends of the tunnel. However, the amount of air delivered and extracted is varied along the length which causes a longitudinal flow in the tunnel itself towards the centre. This is what is normally referred to in modern terminology as a semi-transverse ventilation system where some of the ventilation is provided transversely, and some of the ventilation is provided by using the tunnel itself as a duct longitudinally.

Which pollutants are being addressed?

All pollutants released from road traffic, although NOx, smoke, particulates and possibly CO are of most concern

Maturity of technology

A similar concept is described in Child & Associates 2004 http://www.rta.nsw.gov.au/constructionmaintenance/downloads/2004_10_childrepfiltration.pdf although there may be some novelties suggested in the patent.

Unit cost estimate (Set up)

Transverse tunnel systems are more expensive but often more effective and safer than longitudinal ones, this offers a compromise between the two methods

Unit cost estimate (Maintenance and Operation)

Comment of durability/life cycle

No fundamental difference to other forced ventilation systems

Practicality

Similar systems have been used successfully

Political appeal

These are already used in some form, so not particularly beneficial or controversial

Public acceptability

These are already used in some form, so not particularly beneficial or controversial

Other comments

Possibly a new concept when the patent was first filed (1923) but there seems to be little novelty by comparison with modern tunnel ventilation practices.

Potential for IPL (High/Medium/Low)

Low

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
1	Albred Barthomomai	

Title of Patent

Improvements in or relating to ventilating installations in tunnels

Country	Language	Date	Superseeded	Fees Paid? Y/N
Switzerland	English	1938		

Description of patent

A tunnel ventilation system which extracts polluted air near to ground level, and replenishes air near to the ceiling of the tunnel. The system also has a duct design which allows better distribution of fresh air and a humidifier. This design is claimed to provide more effective ventilation than alternative designs some of which move air in the opposite direction (from bottom to top in transverse designs).

Which pollutants are being addressed?

All vehicle pollutants, however the ones of most importance are NOx, Smoke , particulate and to a lesser extent CO.

Maturity of technology

Not aware of this specific design used anywhere else

Unit cost estimate (Set up)

The general concept does not appear to entail much greater cost than present designs, since it merely involves a reversal in flow from top to bottom. However, the specific patent describes quite complex ductwork to distribute the ventilation air, this is probably now achieved by means of baffles and variable size vents more cheaply. To effectively extract polluted air at the exhaust level may require a more complex ductwork as well.

Unit cost estimate (Maintenance and Operation)

Comment of durability/life cycle

No durability issues

Practicality

As most modern transverse designs ventilate from the bottom to the top of the tunnel, it is assumed this has proved to be the most effective technique for ventilation since the hot exhaust gases will tend to rise. However the concept of extracting air near the exhaust pipe is still interesting, especially if vehicle exhaust designs could be configured to coincide with the extractor ducts (not something described in the patent). Modern tunnel designs must also cater for the incidence of fire. Ventilation systems are also designed to ventilate from bottom to top to extract the smoke away from ground level, these would probably be safer, so the design suggested in the patent may raise safety issues.

Political appeal

If this design raises safety concerns then it would not be politically acceptable

Public acceptability

If this design raises safety concerns then it would not be publicly acceptable

Other comments

Guidelines for current tunnel ventilation designs encourage ventilation in the opposite direction to the design suggested in this patent, although it may be worth further investigation to examine if top to bottom ventilation using appropriate extractor ducts has ever been used successfully. The concept of extracting at exhaust level remains an interesting one for a variety of applications, especially if vehicle exhausts could be configured to suit. Modern computer modelling techniques may be able to cast further light on the feasibility of the concept using different configurations.

Potential for IPL (High/Medium/Low)

Low

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
1	No 47884	

Title of Patent

Ventilation system for a mine or tunnel

Country	Language	Date	Superseeded	Fees Paid? Y/N
Netherlands	Dutch	1940		

Description of patent

A ventilation system for a mine or tunnel consisting of a ventilation shaft and at least 2 turbine fans. Each turbine fan is contained within a duct and mounted on a common carrier framework which can be shifted in such a way that either one or the other fan can be positioned in line with the ventilation shaft and that its duct forms part of the ventilation shaft.

Which pollutants are being addressed?

Vehicle emissions

Maturity of technology

Turbine fans are used widely across the world.

Unit cost estimate (Set up)

Patent claims that the system is less expensive than traditional ventilation systems due to increased efficiency

Unit cost estimate (Maintenance and Operation)

Relatively inexpensive

Comment of durability/life cycle

Once set up would require little maintenance

Practicality

Medium practicality as would require existing ventilation systems in tunnels to be changed

Political appeal

Medium political appeal as it may improve ventilation in tunnels but it would not tackle the air quality problem itself

Public acceptability

Medium public acceptability as may help to improve ventilation in tunnels

Other comments

Low potential for IPL as may help to improve ventilation in tunnels but would not tackle the air quality problem directly.

Potential for IPL (High/Medium/Low)

Low

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
1	Ole Singstad and Herbert G Cruthers	

Title of Patent

Traffic Tunnel and method of tunnel ventilation

Country	Language	Date	Superseeded	Fees Paid? Y/N
USA	English	1947		

Description of patent

An air duct is supplied parallel to the tunnel which is sealed at the middle, so one half can be used to supply air and the other half to exhaust air. This could be classed as a version of what is now known as a semi transverse ventilation system, where some of the ventilation is supplied via ducts positioned along the tunnel and some is passed along the tunnel itself. The system can be reversed in the case of a fire so the ventilation is not directed towards oncoming traffic.

Which pollutants are being addressed?

All vehicle pollutants, however the ones of most importance are NOx, Smoke, particulates and to a lesser extent CO.

Maturity of technology

Semi transverse ventilation systems are already used in tunnels. It is unknown if the specific method proposed has been used.

Unit cost estimate (Set up)

Moderate cost, since a ventilation shaft is required along the length of the tunnel, but only one such shaft is required and no additional inlet duct. This represents an advantage in simplicity over dual duct semi transverse ventilation systems

Unit cost estimate (Maintenance and Operation)

Comment of durability/life cycle

No fundamental difference to other forced ventilation systems.

Practicality

In semi transverse ventilation systems, the UK Design Manual for Roads and Bridges (DMRB) BD 78/99 recommends that the fresh air duct is not used as an exhaust duct. This is due to the time required to reverse the air flow in the air duct.

Political appeal

If there are any safety concerns then there would be less political appeal.

Public acceptability

If there are any safety concerns then there would be less public acceptability.

Other comments

Less useful than a fully transverse system, and probably a variation on the semi transverse system. Not clear if it is entirely novel or safe

Potential for IPL (High/Medium/Low)

Medium

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
1	B Cooper et al	

Title of Patent

Vehicular tunnel ventilation systems

Country	Language	Date	Superseeded	Fees Paid? Y/N
USA	English	1955	N	N

Description of patent

A system to sense and anticipate high CO levels in tunnels and automatically increase the rate of ventilation so as to reduce the CO concentrations to safe levels. This is achieved by sensors and controllers operating the ventilation fans.

Which pollutants are being addressed?

All vehicle pollutants, however the ones of most importance are NOx, Smoke, particulate and to a lesser extent CO.

Maturity of technology

Air quality sensors are now routinely installed inside tunnels to initiate ventilation systems, or to force closure, should predefined pollutant thresholds be exceeded. In the UK, where pollution is measured it is traditionally restricted to smoke/opacity and CO. The sensors, electronic controls and acceptable limits have radically changed since this patent was filed, although the patent refers to the principle of automatic ventilation activation which is still valid.

Unit cost estimate (Set up)

Additional fixed cost for sensors and controller but reduced running costs since a human operator is not required.

Unit cost estimate (Maintenance and Operation)

Comment of durability/life cycle

Automated systems require greater maintenance to avoid breakdowns or poor control.

Practicality

The principle well known and is already used

Political appeal

Irrelevant due to widespread use

Public acceptability

Irrelevant. Unlikely public would know.

Other comments

Clearly the principle has been adopted and adapted and is now widely used.

Potential for IPL (High/Medium/Low)

Low

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
1	William J Caldwell	

Title of Patent

Systems for ventilating tunnels and the like

Country	Language	Date	Superseeded	Fees Paid? Y/N
USA	English	1956	N	N

Description of patent

A directional forced ventilation system for tunnels. Valves direct the airflow from the surface through one of two ducts which supply nozzles pointing either left or right along the axis of the tunnel. The airflow in the longitudinal direction of the tunnel can be reversed depending on the position of the valve. Several such ducts and nozzles are arranged along the tunnel so a substantial airflow can be maintained.

Which pollutants are being addressed?

All vehicle pollutants, however the ones of most importance are NOx, Smoke, particulates, and to a lesser extent CO.

Maturity of technology

Similar directional systems have been used in road tunnels for longitudinal ventilation. Usually fans are oriented along the axis rather than being directed through nozzles.

Unit cost estimate (Set up)

Extra cost of boring ducts between the surface and the tunnel needs to be considered.

Unit cost estimate (Maintenance and Operation)

Comment of durability/life cycle

Most modern tunnel designs have a preference for extracting at the roof of the tunnel (rather than inserting air at the roof as indicated in this design) because of fire regulations. However there is still no reason why the airflow cannot be inserted at ground level. Many modern designs use ducts parallel to the tunnel rather than boring to the surface for ventilation, although in the case of very long tunnels which are not covered by deep water some aspects of the design as proposed in this patent may have some advantages.

Practicality

Probably limited appeal

Political appeal

Probably little concern

Public acceptability

Probably little concern

Other comments

This was primarily designed for railway tunnels. Several aspects of this design are already used.

Potential for IPL (High/Medium/Low)

Low

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
N/A	H H Kress	

Title of Patent

System of ventilation for construction of tunnel

Country	Language	Date	Superseeded	Fees Paid? Y/N
Belgium	French	1956		

Description of patent

Based on the information contained within this patent document and the date filed, it was decided that this patent is not relevant to IPL and is out of date. A decision was made, therefore, to not fully review the patent.

Which pollutants are being addressed?

Maturity of technology

Unit cost estimate (Set up)

Unit cost estimate (Maintenance and Operation)

Comment of durability/life cycle

Practicality

Political appeal

Public acceptability

Other comments

Potential for IPL (High/Medium/Low)

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
N/A	J M Voith	

Title of Patent

Arrangement/Alignment of ventilation (devices) in subterranean road tunnels

Country	Language	Date	Superseeded	Fees Paid? Y/N
Germany	German	1957	N	N

Description of patent

Based on the information contained within this patent document and the date filed, it was decided that this patent is not relevant to IPL and is out of date. A decision was made, therefore, to not fully review the patent.

Which pollutants are being addressed?

Maturity of technology

Unit cost estimate (Set up)

Unit cost estimate (Maintenance and Operation)

Comment of durability/life cycle

Practicality

Political appeal

Public acceptability

Other comments

Potential for IPL (High/Medium/Low)

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
N/A	Lucien Largier-Bruno	

Title of Patent

Installation of ventilation of tunnels

Country	Language	Date	Superseeded	Fees Paid? Y/N
France	French	1963	N	N

Description of patent

Based on the information contained within this patent document and the date filed, it was decided that this patent is not relevant to IPL and is out of date. A decision was made, therefore, to not fully review the patent.

Which pollutants are being addressed?

Maturity of technology

Unit cost estimate (Set up)

Unit cost estimate (Maintenance and Operation)

Comment of durability/life cycle

Practicality

Political appeal

Public acceptability

Other comments

Potential for IPL (High/Medium/Low)

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
N/A	Dr Alex Haerter	

Title of Patent

Air mechanism in road tunnels

Country	Language	Date	Superseeded	Fees Paid? Y/N
Switzerland	German	1967	N	N

Description of patent

Based on the information contained within this patent document and the date filed, it was decided that this patent is not relevant to IPL and is out of date. A decision was made, therefore, to not fully review the patent.

Which pollutants are being addressed?

Maturity of technology

Unit cost estimate (Set up)

Unit cost estimate (Maintenance and Operation)

Comment of durability/life cycle

Practicality

Political appeal

Public acceptability

Other comments

Potential for IPL (High/Medium/Low)

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
1	Horst Fleischer	

Title of Patent

Road tunnel with forced ventilation

Country	Language	Date	Superseeded	Fees Paid? Y/N
Germany	German	1982	Y (DE3117147	Y

Description of patent

A road tunnel longitudinal ventilation system involving forced ventilation. The system consist of an extraction duct connected to a fan and vehicle sensors. The extraction duct itself has a number of openings arranged one behind the other. Each of these openings has a shutter attached to a vehicle sensor. When a vehicle passes the sensor the shutter opens, thus the shutters open one after another. This, in conjunction with vehicle movement creates forced ventilation.

Which pollutants are being addressed?

Vehicle emissions

Maturity of technology

Ventilation systems using extraction ducts are common.

Unit cost estimate (Set up)

May be less expensive than a traditional ventilation system as jet fans are not required

Unit cost estimate (Maintenance and Operation)

Relatively inexpensive

Comment of durability/life cycle

Unknown

Practicality

Medium practicality as would require existing ventilation systems in tunnels to be changed

Political appeal

Medium political appeal as it may improve ventilation in tunnels but it would not tackle the air quality problem itself

Public acceptability

Medium public acceptability as may help to improve ventilation in tunnels

Other comments

Low potential for IPL as may help to improve ventilation in tunnels but would not tackle the air quality problem directly.

Potential for IPL (High/Medium/Low)

Low

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
1	Mitsubishi Denki KK	

Title of Patent

Tunnel Ventilating System

Country	Language	Date	Superseeded	Fees Paid? Y/N
Germany?	English	1986	Y (EP0205979	N (lapsed 1996)

Description of patent

A tunnel ventilating system for ventilating a highway tunnel. Jet fans draw air in from either end of a tunnel towards a vertical shaft mounted towards the centre of the tunnel where the air is expelled by an additional fan. The ventilation rate is governed by a controller which determines the amount of fresh air based on the degree of contamination in the tunnel and other factors.

Which pollutants are being addressed?

All vehicle pollutants, however the ones of most importance are NOx, Smoke , particulates and to a lesser extent CO.

Maturity of technology

This is a variation of a longitudinal ventilation concept with the addition of a central ventilation shaft.

Unit cost estimate (Set up)

The additional cost of a central vertical shaft to the surface may be significant in relation to alternative deigns

Unit cost estimate (Maintenance and Operation)

Comment of durability/life cycle

No significant durability issues relative to conventional designs

Practicality

If the cost of installing a central ventilation shaft can justify the improved air quality it could be an option. This is most likely for shallow tunnels not covered by water.

Political appeal

Local air pollution concentrations may be an issue

Public acceptability

The exit of the central ventilating shaft would concentrate polluted air, so the location of this may have to be carefully considered.

Other comments

This design is similar to Caldwells 1956 patent, except that the vertical shaft expels rather than supplies air from the surface and air is always drawn towards the centre rather than being uni-directional. It is also similar to the Cooper et al 1956 patent in that the ventilation system is automatically controlled depending upon the pollutant concentration.

Potential for IPL (High/Medium/Low)

Medium

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
5	Norman Lesser and Fred Horowitz	

Title of Patent

Totally fusible tunnel ventilation damper system

Country	Language	Date	Superseeded	Fees Paid? Y/N
USA	English	1990	N	N (expired 2006)

Description of patent

Panels (windows or ventilation dampers) are secured using fusible material (sealant which melts or vaporizes at a low temperature). This allows the panels to automatically open in the event of fire and allow the smoke to escape through ducts.

Which pollutants are being addressed?

CO, Smoke, particulate, any pollutants from a fire

Maturity of technology

Unit cost estimate (Set up)

Unit cost estimate (Maintenance and Operation)

Comment of durability/life cycle

Practicality

Political appeal

Public acceptability

Other comments

This is a system for smoke control in the event of a fire, so it is unclear if this should be assessed for tunnel pollution control. However, this raises the issue why are these vents sealed in the first place, could they be used for ventilation and additional pollution control in some circumstances?

Potential for IPL (High/Medium/Low)

Low

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
3	Anders Krantz	Airchtect I Soderhamn AB

Title of Patent

Method & installation for air treatment in the area of a traffic route for motor vehicles

Country	Language	Date	Superseeded	Fees Paid? Y/N
Sweden	English	1990	N	N

Description of patent

An air quality improvement system involving the encapsulation of heavily trafficked roads/interchanges in a shell like structure. The exhaust air from vehicles is sucked through an outlet at a low level (allowing for the entrainment of gases and their constituents e.g. sulphur dioxide, carbon dioxide, nitric oxide, nitrogen dioxide and lead) and passed to air treatment stations. In an air treatment station the air is passed through 2 sets of filters (filter tubes may contain different types of absorbents such as active carbon or grains of the PURAFIL type). The filtered air is then passed out to into the atmosphere. Fresh air enters the shell through lower and upper inlets to create air currents and can be controlled through the use of dampers.

Which pollutants are being addressed?

Patent claims to address all vehicle exhaust pollutants e.g. sulphur dioxide, carbon dioxide, nitric oxide, nitrogen dioxide and lead.

Maturity of technology

Not very mature

Unit cost estimate (Set up)

It is claimed that the set up of this system would be less expensive than re-routing roads to reduce localised air pollution,

Unit cost estimate (Maintenance and Operation)

Cost of filters and maintenance

Comment of durability/life cycle

Filters would need replacing regularly. Shell providing it is made out of sturdy material should last but the maintenance/ cleaning requirements would need consideration.

Practicality

Medium practicality as would help to solve air quality problems on existing road systems. It could potentially reduce the need for the rerouting of roads.

Political appeal

Potentially high political appeal. It would be innovative and would reduce air quality problems, reduced noise impacts and also potentially improve road safety.

Public acceptability

Medium public acceptability as would improve air quality, noise impacts and potentially make roads safer. It would, however, have a visible impact on the landscape and could be disruptive during construction.

Other comments

A very adaptable idea. Can be used on existing roads and interchanges to reduce air quality impacts. In addition, it can help to reduce noise impacts on the local community and improve road safety through environmental control (e.g. reduced road slippage in wet weather conditions). However, there are concerns about: disposal of absorbers, maintenance implications, range of pollutants addressed, energy and cost of operating. Likely to be most suitable for pollution hotspots rather than across a large part of the network.

Potential for IPL (High/Medium/Low)

High

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
1	Richard D Matthews	

Title of Patent

Air Moving System

Country	Language	Date	Superseeded	Fees Paid? Y/N
USA	English	1998	N	N (Expired 2002)

Description of patent

A tunnel ventilation system comprising of jet fans being able to move on their axis to ensure that air flow is always directed away from supporting surfaces. This is particularly important in conditions where reverse thrust is required e.g. smoke/toxic chemical release.

Which pollutants are being addressed?

Vehicle emissions and smoke

Maturity of technology

Tunnel ventilation and jet fans are used across the world.

Unit cost estimate (Set up)

Expensive to install any ventilation system

Unit cost estimate (Maintenance and Operation)

Relatively low maintenance and operation cost

Comment of durability/life cycle

Jet fans are used across the world and are relatively reliable

Practicality

Very practical

Political appeal

Medium appeal as would not be a visible innovation. It would, however, potentially make ventilation more efficient and would allow safety zones to produced more easily in emergencies.

Public acceptability

High acceptability as little visible change, would improve ventilation in the tunnel, and would make the tunnel safer in emergencies.

Other comments

Medium appeal to DWW as would only improve ventilation in tunnels and not actually treat the air pollution.

Potential for IPL (High/Medium/Low)

Medium

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
2	Saito Makoto	

Title of Patent

Method for cleaning contaminated air in tunnel

Country	Language	Date	Superseeded	Fees Paid? Y/N
Japan	Eng/Japanese	2000		

Description of patent

This system appears to use fans to blow air in the opposite direction to the traffic flow to deliberately slow down overall ventilation in and out of the tunnel orifices so as to increase the concentration of pollutants in the tunnel. Perhaps this is to achieve concentrations which can be economically removed by an air cleaner

Which pollutants are being addressed?

All tunnel pollutants

Maturity of technology

Uses conventional technologies but method appears to be counterintuitive

Unit cost estimate (Set up)

Possibly low in relation to other technologies

Unit cost estimate (Maintenance and Operation)

Possibly low in relation to other technologies

Comment of durability/life cycle

No major issues

Practicality

This appears to increase tunnel pollutant concentrations so appropriate devices can be used to clean the outlet air. Obviously if the concentrations in the tunnel were above acceptable limits this would be unsatisfactory.

Political appeal

Would probably be controversial

Public acceptability

Acceptable to outside residents but probably unacceptable to drivers

Other comments

This patent seems counterintuitive.

Potential for IPL (High/Medium/Low)

Low

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
1	Hiroyuki Ohashi	

Title of Patent

System and method for controlling ventilation in a tunnel

Country	Language	Date	Superseeded	Fees Paid? Y/N
USA	English	2001	N	N (Expired 2005)

Description of patent

A tunnel ventilation system that involves the controlling of vehicle speed in the tunnel to improve ventilation efficiency and utilise ventilation by vehicle traffic (e.g. if vehicles in the ventilation direction are moving faster than those on the other side of the road it is possible to strengthen ventilation). The vehicle speed is based upon air flow velocity, air pollution levels, and vehicle numbers, and is sent to vehicles via a sensor.

Which pollutants are being addressed?

All vehicle exhaust emissions and smoke

Maturity of technology

Not very mature in this context. Controlling speeds through active traffic management, however, is quite well advanced.

Unit cost estimate (Set up)

Potentially expensive to install

Unit cost estimate (Maintenance and Operation)

Relatively low maintenance and operation cost

Comment of durability/life cycle

Once set up would require little maintenance

Practicality

Low practicality as would require vehicles to be fitted with additional features to be fully functional. Although there is some argument for vehicles fitted with the required devices slowing the other vehicles down to the required speed.

Political appeal

Low appeal as would require all vehicles to be fitted with leaky coaixal controllers, and throttle and brake actuators to be fully functional. It would, however, improve tunnel ventilation, and could potentially improve safety due to the speed of cars being controlled.

Public acceptability

Low appeal as would require all vehicles to be fitted with leaky coaixal controllers, and throttle and brake actuators to be fully functional. It would, however, improve tunnel ventilation, and could potentially improve safety due to the speed of cars being controlled.

Other comments

Low appeal as would require all vehicles to be fitted with leaky coaixal controllers, and throttle and brake actuators. Although there is some argument for vehicles fitted with the required devices slowing the other vehicles down to the required speed. DWW may wish to consider using the principle in this patent but using variable speed limits in the tunnels instead of controlling vehicle speeds directly.

Potential for IPL (High/Medium/Low)

Low

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
2	Rud Otto Meyer Gmbh & Co Kg	

Title of Patent

Method and suction system for ventilation, i.e. smoke suction in tunnels

Country	Language	Date	Superseeded	Fees Paid? Y/N
Germany	German	2000	Y (EP1081331	Y (lapsed 2006)

Description of patent

An air suction and ventilation system for tunnels. This involves the setting up of an acquisition flow in the upper third of a tunnels' cross section in such a way that uniform acquisition is achieved. Air is sucked out radially or tangentially and fed to an outlet channel in the roof of the tunnel

Which pollutants are being addressed?

Vehicle emissions and smoke

Maturity of technology

Ventilation systems based on this concept have been preciously used.

Unit cost estimate (Set up)

All ventilation systems are expensive to install initially

Unit cost estimate (Maintenance and Operation)

Relatively low maintenance and operation cost

Comment of durability/life cycle

Once set up would require little maintenance

Practicality

Medium practicality as would require existing ventilation systems in tunnels to be changed

Political appeal

Medium political appeal as it may improve ventilation in tunnels but it would not tackle the air quality problem itself

Public acceptability

Medium public acceptability as may help to improve ventilation in tunnels

Other comments

Low potential for IPL as may help to improve ventilation in tunnels but would not tackle the air quality problem directly. If the outlet was connected to a cleaning device this may be more applicable to DWW.

Potential for IPL (High/Medium/Low)

Low

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
5	Josip Pavetic	

Title of Patent

Process for the ventilation of road tunnel

Country	Language	Date	Superseeded	Fees Paid? Y/N
Germany	English	2000	N	N (Deemed to be

Description of patent

Road tunnel ventilation system suitable for use during fires.

Which pollutants are being addressed?

Gas, particulates and water drops (primarily in fire conditions)

Maturity of technology

Unit cost estimate (Set up)

Unit cost estimate (Maintenance and Operation)

Comment of durability/life cycle

Practicality

Political appeal

High as decreased risk to public in fire conditions

Public acceptability

Acceptable as decreases risk to public in fire conditions in tunnels

Other comments

Not really applicable to the IPL programme as is a system for the ventilation of tunnels that can be used in fire conditions. Although could potentially increase ventilation efficiency.

Potential for IPL (High/Medium/Low)

Low

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
5	Hartmut Ewald et al	

Title of Patent

Method and device for extracting fumes and heat and for providing operational for traffic structures and enclosed traffic spaces

Country	Language	Date	Superseeded	Fees Paid? Y/N
USA	English	1999	N	Y

Description of patent

Road tunnel ventilation system suitable for use during fires an high pollution episodes. This system involves an innovative method of fume extraction overcoming many of the current issues associated with current fire ventilation systems utilising pipe ventilators (e.g. the need for decreased pressure, leakages, loss of system function). This system involves a fume extraction duct with water and evaporative cooling systems to reduce temperatures and the volume of fumes. The density of the fumes change and the intensity of the jet ventilators is therefore enhanced. A dynamic reduced pressure is continuously produced by the Bernoulli principle thus meaning that in the event of a fire/high pollution incident the ventilation system can work immediately, and leakages will not affect it.

Which pollutants are being addressed?

Gases, smoke and particulates (particularly in fire conditions)

Maturity of technology

Ventilation using jet fans is widely used.

Unit cost estimate (Set up)

All ventilation systems are expensive to install initially

Unit cost estimate (Maintenance and Operation)

Maintenance and operation costs potentially lower than traditional ventilation equipment due to equipment involved in the system being additionally protected from fire through the cooling mechanisms

Comment of durability/life cycle

Once set up would require little maintenance

Practicality

Medium practicality as would require new ventilation systems to be installed in existing tunnels

Political appeal

Medium appeal as would not be a visible innovation. It would, however, potentially make ventilation more efficient and would allow safety zones to be produced more easily in emergencies.

Public acceptability

High acceptability as little visible change, would improve ventilation in the tunnel, and would make the tunnel safer in emergencies.

Other comments

Low appeal to DWW as is primarily an innovative idea for ventilation in fires and does not actually treat the air. It is stated, however, that when combined with the "Method for purifying outgoing air by removing particles and gases" DE196 46 766 7 this could help to improve air quality.

Potential for IPL (High/Medium/Low)

Low

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
1	Frank Lehnhaeuser and Volkhard Nobis	

Title of Patent

Suction device for a tunnel

Country	Language	Date	Superseeded	Fees Paid? Y/N
Germany	German	2002	N	Y

Description of patent

A suction device for a tunnel. The system aims to be relatively cheap, simple and safe. The system comprises of one vortex hood which is embodied as a portal.

Which pollutants are being addressed?

Vehicle emissions and smoke

Maturity of technology

Ventilation systems involving suction devices are commonly used

Unit cost estimate (Set up)

Patent claims that that the suction device is cheap and easy to fit

Unit cost estimate (Maintenance and Operation)

Relatively inexpensive

Comment of durability/life cycle

Once set up would require little maintenance

Practicality

Medium practicality as would require existing ventilation systems in tunnels to be changed

Political appeal

Medium political appeal as it may improve ventilation in tunnels but it would not tackle the air quality problem itself

Public acceptability

Medium public acceptability as may help to improve ventilation in tunnels

Other comments

Low potential for IPL as may help to improve ventilation in tunnels but would not tackle the air quality problem directly.

Potential for IPL (High/Medium/Low)

Low

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
N/A	Astrid Gande	

Title of Patent

Mechanism for the regulation of the ventilation in a tunnel

Country	Language	Date	Superseeded	Fees Paid? Y/N
Germany	German	2002		N

Description of patent

Based on the information contained within this patent document and the date filed, it was decided that this patent is not relevant to IPL and is out of date. A decision was made, therefore, to not fully review the patent.

Which pollutants are being addressed?

Maturity of technology

Unit cost estimate (Set up)

Unit cost estimate (Maintenance and Operation)

Comment of durability/life cycle

Practicality

Political appeal

Public acceptability

Other comments

Potential for IPL (High/Medium/Low)

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
1	Frank Lehnhaeuser and Volkhard Nobis	

Title of Patent

Suctioning device for a tunnel

Country	Language	Date	Superseeded	Fees Paid? Y/N
Germany	German	2002	N	N

Description of patent

A suction device for a tunnel. The system aims to be cheap and easy to fit to both new and existing tunnels. The system comprises of two vortex hoods which are fixed in the tunnel between the upper and lower limit of the tunnel.

Which pollutants are being addressed?

Vehicle emissions and smoke

Maturity of technology

Ventilation systems involving suction devices are commonly used

Unit cost estimate (Set up)

Patent claims that that the suction device is cheap and easy to fit

Unit cost estimate (Maintenance and Operation)

Relatively inexpensive

Comment of durability/life cycle

Once set up would require little maintenance

Practicality

Medium practicality as would require existing ventilation systems in tunnels to be changed

Political appeal

Medium political appeal as it may improve ventilation in tunnels but it would not tackle the air quality problem itself

Public acceptability

Medium public acceptability as may help to improve ventilation in tunnels

Other comments

Low potential for IPL as may help to improve ventilation in tunnels but would not tackle the air quality problem directly.

Potential for IPL (High/Medium/Low)

Low

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
1	Dennis T Griggs	

Title of Patent

Covered highway structure with means for easy and quick access to tunnel interior

Country	Language	Date	Superseeded	Fees Paid? Y/N
USA	English	2003		

Description of patent

Covered highway structure with means for easy and quick access to tunnel interior: (with internal barrier between carriageways and air deflectors at exit to make use of the "piston effect" of vehicles moving the polluted air)

Which pollutants are being addressed?

All air pollutants and noise

Maturity of technology

Method as used immature. Tunnel materials and use of air deflectors unknown.

Unit cost estimate (Set up)

Possibly less than the cost of building a channel or underground tunnel, but these are often performed to bypass infrastructure. Overall cost depends on tunnel design (strength required, design and materials).

Unit cost estimate (Maintenance and Operation)

Comment of durability/life cycle

Tunnel could be susceptible to adverse weather conditions unless it is made from more sturdy material than suggested which may add substantial cost.

Practicality

Placing a barrier between traffic and pedestrians at street level should reduce the personal impact of pollution and noise. There is a potential problem of concentrating pollution at tunnel exits if the air deflectors don't work. Noise reduction effectiveness will depend on the density and thickness of tunnel.

Political appeal

Some political appeal in reducing local air pollution if it works.

Public acceptability

May restrict pedestrian access and cause community severance. Crossings may have to be elevated or underground.

Other comments

Difficult to assess the effectiveness of air deflectors without modelling studies (e.g. wind tunnel experiments). Likely to be most suitable for pollution hotspots rather than across a large part of the network. Prevailing wind directions would need to be taken into account.

Potential for IPL (High/Medium/Low)

Medium

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
1	Alexander Fasnacht	

Title of Patent

Device for introducing breathing air in a tunnel passageway

Country	Language	Date	Superseeded	Fees Paid? Y/N
Germany	German	2002	N	Y (Withdrawn 20

Description of patent

This patent describes a system of introducing fresh air into tunnels, especially in emergency situations.

Which pollutants are being addressed?

N/A

Maturity of technology

Ventilation systems involving feed lines are commonly used

Unit cost estimate (Set up)

Potentially expensive

Unit cost estimate (Maintenance and Operation)

Relatively inexpensive

Comment of durability/life cycle

Once set up would require little maintenance

Practicality

Medium practicality

Political appeal

Medium appeal as would help to bring in fresh air

Public acceptability

Medium appeal as would help to bring in fresh air

Other comments

Low appeal as would not tackle the air quality problem

Potential for IPL (High/Medium/Low)

Low

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
5	Walter Diener	

Title of Patent

Fire fighting system has suction openings and outlets for heat, smoke and fumes, with natural air-currents

Country	Language	Date	Superseeded	Fees Paid? Y/N
Germany	German	2003	N	Y

Description of patent

A fire barrier system involving compressors which open shutters near the fire source. Turbines are turned on causing the air to flow downward so combat the fire and suck up the smoke.

Which pollutants are being addressed?

Smoke and poisonous fumes

Maturity of technology

Fire systems utilising this sort of technique are commonly used

Unit cost estimate (Set up)

All fire ventilation systems are expensive to install

Unit cost estimate (Maintenance and Operation)

Relatively inexpensive

Comment of durability/life cycle

Once set up would require little maintenance

Practicality

Medium practicality

Political appeal

Medium appeal as would make fire situations safer

Public acceptability

Medium appeal as would make fire situations safer

Other comments

Low appeal as would not tackle the air quality problem

Potential for IPL (High/Medium/Low)

Low

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
5	Volkhard Nobis	

Title of Patent

Smoke extraction system at a tunnel roof, to extract smoke from a fire by suction in an eddy hood structure, has an angled apron flanking the suction opening(s) to direct the rising smoke into them

Country	Language	Date	Superseeded	Fees Paid? Y/N
Germany	German	2003	Y (DE1022423	Y

Description of patent

A smoke extraction system comprising an eddy hood smoke extractor and an angled apron to guide the smoke to the suction openings.

Which pollutants are being addressed?

Smoke and poisonous fumes

Maturity of technology

Unit cost estimate (Set up)

All suction devices are expensive to install

Unit cost estimate (Maintenance and Operation)

Relatively inexpensive

Comment of durability/life cycle

Once set up would require little maintenance

Practicality

Medium practicality

Political appeal

Medium appeal as would make fire situations safer

Public acceptability

Medium appeal as would make fire situations safer

Other comments

Low appeal as would not tackle the air quality problem

Potential for IPL (High/Medium/Low)

Low

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
5	Kickelhayn, Horst	

Title of Patent

System to improve the atmosphere in a tunnel, especially at an underground station

Country	Language	Date	Superseeded	Fees Paid? Y/N
Germany	German	2004	N	N

Description of patent

A system to improve the atmosphere, and reduce the heat in tunnels especially underground tunnels. The heat from the air passes over a liquid conveying lining to the cooling liquid (ideally water) which removes the heat from the air

Which pollutants are being addressed?

Heat

Maturity of technology

Systems of this type are not widely used in tunnels

Unit cost estimate (Set up)

Potentially expensive

Unit cost estimate (Maintenance and Operation)

Relatively in expensive

Comment of durability/life cycle

Once set up would require little maintenance

Practicality

Medium practicality as would cause disruption to rail networks

Political appeal

Low appeal as would not improve the air quality problem

Public acceptability

Medium appeal as would not improve the air quality problem but would make conditions in underground train stations better

Other comments

Low appeal as would not tackle the air quality problem

Potential for IPL (High/Medium/Low)

Low

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
1	Torsten Bachmann et al	

Title of Patent

Method and device for ventilating a tunnel

Country	Language	Date	Superseeded	Fees Paid? Y/N
Germany	German	2002	N	Y (due to be with

Description of patent

A tunnel ventilation system comprising an upper duct (separated from the road space) with closable flaps. In fire conditions the flaps above the fire can be opened and all the others closes in order to extract the fumes.

Which pollutants are being addressed?

Smoke and poisonous fumes

Maturity of technology

Unit cost estimate (Set up)

All fire ventilation systems are expensive to install

Unit cost estimate (Maintenance and Operation)

Relatively inexpensive

Comment of durability/life cycle

Once set up would require little maintenance

Practicality

Medium practicality

Political appeal

Medium appeal as would make fire situations safer

Public acceptability

Medium appeal as would make fire situations safer

Other comments

Low appeal as would not tackle the air quality problem

Potential for IPL (High/Medium/Low)

Low

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
5	Volkhard Nobis	

Title of Patent

Suction device comprising a fire protection system

Country	Language	Date	Superseeded	Fees Paid? Y/N
Germany	German	2002	N	Y

Description of patent

This system comprises a suction device suitable for use during fire conditions in road tunnels. The suction device is designed with nozzles in the vortex hood that spray a mist of fine droplets into the air, and prevent the system from becoming damaged in the event of a fire.

Which pollutants are being addressed?

Smoke and poisonous fumes

Maturity of technology

Unit cost estimate (Set up)

All suction devices are expensive to install

Unit cost estimate (Maintenance and Operation)

Relatively inexpensive

Comment of durability/life cycle

Once set up would require little maintenance

Practicality

Medium practicality

Political appeal

Medium appeal as would make fire situations safer

Public acceptability

Medium appeal as would make fire situations safer

Other comments

Low appeal as would not tackle the air quality problem

Potential for IPL (High/Medium/Low)

Low

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
3	Fuji Electric Co Ltd	

Title of Patent

Ventilating device for motorway tunnel

Country	Language	Date	Superseeded	Fees Paid? Y/N
Japan	Eng/Japanese	1991		

Description of patent

This ventilation system comprises a system to eliminate dusts and noxious gases from air in motorway tunnels. The system consists of an electrified dust collector and a noxious gas eliminating device (containing a reaction tube consisting of glass with Tio2 powder, active carbon powder, and Fe2O3 powder with a light source in 300-400nm wavelength. The noxious gases adhere to the reaction tube 21. The dust collector and noxious gas eliminator are connected to the tunnel via a suction port and a discharge port.

Which pollutants are being addressed?

A range of vehicle emissions are addressed.

Maturity of technology

Fairly immature technology

Unit cost estimate (Set up)

Expensive to install

Unit cost estimate (Maintenance and Operation)

Reaction tubes would need replacing

Comment of durability/life cycle

Reaction tubes would need replacing with waste management implications. Potentially high energy costs.

Practicality

Medium practicality

Political appeal

Medium appeal as would help to reduce air pollution impacts in and around tunnels

Public acceptability

High appeal as would improve air quality in the local area both for drivers and residents.

Other comments

Worth exploring further. Note that PIARC working group have initiated trials using electrostatic precipitators (part of this patent technology). Transferability to non tunnel environments would need investigating. Further investigation could be informed by desktop analysis.

Potential for IPL (High/Medium/Low)

High

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
2	Kawasaki Heavy Ind Ltd	

Title of Patent

Method and apparatus for purifying exhaust gas

Country	Language	Date	Superseeded	Fees Paid? Y/N
Japan	Eng/Japanese	1993		

Description of patent

Ozone is mixed with exhaust gas so the NO is converted to NO2 which is absorbed in tanks using manganese oxide-activated alumina. A high temperature air circulating system is then passed through the tanks (possibly one is being desorbed whilst the other is adsorbing?) which releases NOx and regenerates the absorbent. The gas is then passed through a selective catalytic reactor were the NOx is then decomposed into N2 and H20.

Which pollutants are being addressed?

NO/NO2

Maturity of technology

Uses several techniques mentioned in other patents but this uses them in combination.

Unit cost estimate (Set up)

Difficult to comment without more details

Unit cost estimate (Maintenance and Operation)

Comment of durability/life cycle

NOx catalysts and absorbers may have a limited lifespan, perhaps less than 10 years.

Practicality

Treating tunnel exhaust gas is difficult due to the low concentrations of pollutants and large volumes of gas involved. This process could be more effective than other techniques if it can concentrate the NOx for catalytic action, however without a more detailed investigation it is difficult to determine if the process proposed it is likely to be effective or cost effective. The process could be designed for treating gases with higher concentrations of pollutants than in tunnels.

Political appeal

Some appeal if it works and is cost effective, however this reduces pollution from the outlet ducts not within the tunnel itself

Public acceptability

No acceptability problems providing the process works effectively

Other comments

Potential for IPL (High/Medium/Low)

Medium

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
3	Matsushita Electric Ind Co Ltd	

Title of Patent

NOX and SOX purging device and its maintenance method

Country	Language	Date	Superseeded	Fees Paid? Y/N
Japan	Eng/Japanese	1995		

Description of patent

A system to remove nitrogen oxides and sulphur dioxides from polluted air in tunnels. The polluted air passes over an electrode plate whereby oxidisation occurs. The oxidised gases then pass over 2 beds of a dry absorbent containing an alkaline component. The gases are absorbed and the air cleaned.

Which pollutants are being addressed?

Nitrogen oxides and sulphur dioxides

Maturity of technology

The technology involved with oxidisation and absorption for polluted gases in tunnels is relatively new.

Unit cost estimate (Set up)

Potentially expensive

Unit cost estimate (Maintenance and Operation)

Relatively inexpensive to operate and maintain

Comment of durability/life cycle

Energy use would be required to power the electrode, and absorbent beds may need to be replaced

Practicality

Medium practicality

Political appeal

Medium appeal as would help to reduce air pollution impacts in and around tunnels

Public acceptability

High appeal as would improve air quality in the local area both for drivers and residents.

Other comments

The principles involved in oxidising NOx and SOx, rather than particles, need further investigation to justify the claimed benefits. Treatment of SOx less relevant to current vehicle emission problems. More investigation is needed to understand and review the potential of this technology.

Potential for IPL (High/Medium/Low)

Medium

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
2	Ishikawa Harima Heavy Ind	

Title of Patent

Purification device for air in tunnel

Country	Language	Date	Superseeded	Fees Paid? Y/N
Japan	Eng/Japanese	1996		

Description of patent

A fan and pollution treatment process is contained in the same unit. This can be mounted in a tunnel avoiding the need for ventilation shafts. The integral fan unit is mounted on a rotating swivel so the direction of flow can be reversed. The exhaust treatment includes an electrostatic dust collector at the inlet and an ozone generator on the outlet.

Which pollutants are being addressed?

Sox, Nox, particulates

Maturity of technology

Similar fans are already used but not with integral exhaust treatment

Unit cost estimate (Set up)

The integral nature of the fan and exhaust treatment process avoids the need for shafts and external exhaust treatment.

Unit cost estimate (Maintenance and Operation)

Comment of durability/life cycle

Difficult to determine since there is not a full description of the exhaust treatment processes in English

Practicality

Electrostatic particulate removal is more effective at low gas velocities, hence the removal device is usually quite large. An tunnel mounted fan needs to be compact to provide clearance for the traffic, it is difficult to see how an electrostatic device could be effective in such a small device. Whilst ozone generation can be used to promote chemical reactions for subsequent processes which can remove pollutants, it is unclear what the purpose of the ozone is in this case (at the outlet) which could potentially increase pollution. However, some information may have been lost in the translation.

Political appeal

Low

Public acceptability

Low

Other comments

Potential for IPL (High/Medium/Low)

Low

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
5	Karl Dickels	

Title of Patent

To filter device for the separation of particles and of with break developing gas from air in road tunnels or in raumen

Country	Language	Date	Superseeded	Fees Paid? Y/N
Germany	German	1996	N	N

Description of patent

This filter system is suitable for the filtration of particles and fire-generated gases from air in tunnels or spaces. The system consists of an electrostatic filter (for particles) and a gas filter which comes into use only in fire conditions. The gas filter is pivot mounted and is held by a connection. The connection should ideally consist of a solder which would melt at a pre-determined temperature or a retaining magnet. When this temperature is met the solder would melt and the gas filter would be allowed to move into the air stream.

Which pollutants are being addressed?

Particulates and fire-generated gases.

Maturity of technology

Electrostatic filters have been used in industry for years but this is a relatively new technology when it comes to tunnels

Unit cost estimate (Set up)

Relatively expensive to install

Unit cost estimate (Maintenance and Operation)

Large amounts of energy would be required to power the electrostatic precipitator

Comment of durability/life cycle

Large amounts of energy would be required to power the electrostatic precipitator

Practicality

Medium practicality

Political appeal

Medium political appeal as would not only improve air quality under normal conditions, but would help to reduce the impact of fire episodes on the local air quality.

Public acceptability

High public acceptability as would not be visually intrusive, and would help to improve air quality

Other comments

Questionable in potential to improve local air quality on a widespread basis.

Potential for IPL (High/Medium/Low)

Low

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
3	Aiken Kogyo KK	

Title of Patent

Non-blower type air purifier in tunnel

Country	Language	Date	Superseeded	Fees Paid? Y/N
Japan	Eng/Japanese	1998		

Description of patent

This system involves the use of electrostatic precipitation. Polluted air travels through an intake port into a path underneath the road / or in the tunnel wall. The polluted air is forced through the area by the force of the vehicle above or next to the intake port. The air then passes through the precipitator and out a discharge port.

Which pollutants are being addressed?

Vehicle emissions and dust

Maturity of technology

Electrostatic precipitation has been used in industry for years but this is a relatively new technology when it comes to tunnels

Unit cost estimate (Set up)

Relatively expensive to install

Unit cost estimate (Maintenance and Operation)

Large amounts of energy would be required to power the electrostatic precipitator. Cheaper to run than some systems involving electrostatic precipitators due to the lack of fans to blow air across the precipitator.

Comment of durability/life cycle

Large amounts of energy would be required to power the electrostatic precipitator

Practicality

Medium practicality

Political appeal

Medium political appeal as would improve air quality

Public acceptability

High public acceptability as would not be visually intrusive, and would help to improve air quality

Other comments

Effectiveness of "non-blower" (passive airflow) would need to be proven. Otherwise the electrostatic precipitator technology is not novel. Elevated decks in tunnels may present fire risks.

Potential for IPL (High/Medium/Low)

Medium

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
2	Atsushi Katatani	Matsushita Electric Ind Co Ltd

Title of Patent

Denitrification system

Country	Language	Date	Superseeded	Fees Paid? Y/N
European	English	1994	Y (EP0627253	Y

Description of patent

A denitrification system comprising an electrostatic precipitator, an ozonizer, and ozone supply nozzle, a fan, a humidifier and humidity sensor, and a NO2 absorbent filter. The exhaust gases are passed first through the electrostatic precipitator to remove dust and soot, then mixed with the ozone produced by the ozonizer in order to convert NO to NO2 and finally through the NO2 absorbent filter. The humidifier and humidity sensor allow for humidity to be kept at the optimum level for the denitrification process. This system helps to overcome many of the issues associated with conventional denitrification systems e.g. soot and dust build up on the filter and humidity variance.

Which pollutants are being addressed?

NO2, SO2, NO and dust

Maturity of technology

As of 2004, the operational use of denitrification technology in road tunnels has been limited to a system supplied by Alstom in the Laerdal Tunnel, Norway. The performance of this system has been difficult to assess as the traffic and pollutant levels in this tunnel are relatively low.

Unit cost estimate (Set up)

Potentially expensive

Unit cost estimate (Maintenance and Operation)

Relatively low maintenance and operational cost

Comment of durability/life cycle

Once set up would require disposal of dust particles.

Practicality

Medium practicality

Political appeal

High political appeal as would be one of the first countries to use this in tunnels commercially and has the potential to significantly improve air quality in tunnels

Public acceptability

Medium public acceptability as may cause some disruption to the road network during installation

Other comments

A complex patent but is worth exploring further. It is important to note that alternative versions of this system could be produced e.g. you can use chemical absorption or a catalytic process to remove NO2. It is also possible to remove hydrocarbons such as benzene if a catalytic process or activated carbon is used.

Potential for IPL (High/Medium/Low)

High

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
2	Matsuda Satoshi	

Title of Patent

Exhaust gas treating device

Country	Language	Date	Superseeded	Fees Paid? Y/N
Japan	Eng/Japanese	2005		

Description of patent

An exhaust gas treatment device capable of treating oxides of nitrogen in an exhaust gas at normal temperature. An oxidising agent (ozone) is supplied to the exhaust stream where it then passes through a fluid absorbent. The process also appears to use 'particles' and an 'optical catalyst' as part of the treatment process, but the details are unclear from the summary.

Which pollutants are being addressed?

NOx, particulates, CO

Maturity of technology

Uses several techniques mentioned in other patents but this uses them in combination.

Unit cost estimate (Set up)

Difficult to comment without more details

Unit cost estimate (Maintenance and Operation)

Comment of durability/life cycle

Difficult to comment without more details

Practicality

The use of oxidising agents, adsorbents and optical catalysts have all been used as part of exhaust treatment process. Therefore it appears as if this invention may be worth further examination

Political appeal

Difficult to comment without more details

Public acceptability

Difficult to comment without more details

Other comments

This appears to be oriented towards the exhaust treatment of industrial processes with lower flows and higher concentrations than found in tunnels, however it is possible hat the methodology could be adapted for this purpose.

Potential for IPL (High/Medium/Low)

Medium

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
3	Bruce White et al	

Title of Patent

Procedure and device for the ventilation of tunnels

Country	Language	Date	Superseeded	Fees Paid? Y/N
France	French	1996	N	N

Description of patent

A system to improve the ventilation in tunnels and to remove the carbon monoxide and carbon dioxide from the air within the tunnel. It is proposed that this is performed by cooling the polluted air, extracting the condenses water vapour, oxidising the carbon monoxide, extracting the remaining carbon dioxide, and reinstating the oxygen content of the purified air. The carbon dioxide is separated from the air by gravity, and then compressed and liquefied before being pumped out of the tunnel. The air is cooled by the use of heat exchangers and the use of liquid oxygen. The liquid oxygen is boiled by the use of the heat in the exchanger and mixed with the purified air to reinstate the oxygen content. Liquid nitrogen can be used to control the amount of oxygen entering the purified air.

Which pollutants are being addressed?

Carbon monoxide and carbon dioxide

Maturity of technology

This method is not widely used

Unit cost estimate (Set up)

Relatively high

Unit cost estimate (Maintenance and Operation)

The use of liquid nitrogen and oxygen may be expensive

Comment of durability/life cycle

Liquid oxygen and nitrogen would need replacing regularly

Practicality

Medium practicality

Political appeal

Medium political appeal as would improve air quality in tunnels

Public acceptability

High public acceptability as would not be visually intrusive, and would help to improve air quality

Other comments

Could potentially improve air quality in tunnels but does not address Nox and PM10s

Potential for IPL (High/Medium/Low)

Medium

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
2	Daido Steel Co Ltd	

Title of Patent

Apparatus for cleaning exhaust gas from automobile tunnel

Country	Language	Date	Superseeded	Fees Paid? Y/N
Japan	Eng/Japanese	1989		

Description of patent

A system to remove harmful gases and dust from vehicle emissions in tunnels. It consists of an exhaust gas treating duct containing air filters for dust removal and a spray system for impregnating the upstream of the air filters with an oxidation-reduction agent.

Which pollutants are being addressed?

Vehicle emissions and particulates

Maturity of technology

The oxidation-reduction reaction is well known but the constituents of the process are not clearly defined.

Unit cost estimate (Set up)

Relatively high

Unit cost estimate (Maintenance and Operation)

Filters and oxidation-reduction agent would need replacing regularly

Comment of durability/life cycle

Filters and oxidation-reduction agent would need replacing regularly

Practicality

Medium practicality

Political appeal

Medium political appeal as would improve air quality

Public acceptability

High public acceptability as would not be visually intrusive, and would help to improve air quality

Other comments

Not enough information to conclude whether the technique would be effective. Technology may have been superseded based on the age of the patent.

Potential for IPL (High/Medium/Low)

Medium

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
4	Chester L Foster	

Title of Patent

Method and apparatus for treating polluted air along auto traffic arteries

Country	Language	Date	Superseeded	Fees Paid? Y/N
USA	English	1975	N	N

Description of patent

A system for treating ambient air (particularly around heavily trafficked roads in urban areas) by collecting the polluted air by an appropriate input mechanism and directed through portions of storm sewer air passageways. This is then directed towards an air treatment plant where the air is washed, scrubbed, treated and filtered (through activated charcoal) and then redistributed back to the road by an appropriate outlet duct system. The movement of air through the system is made by using a suction-blowing fan. The aim is to trap as much of the air pollutant material info a water solution that can be easily disposed of through the conventional sewage system.

Which pollutants are being addressed?

All pollutant gases and particulates

Maturity of technology

This idea is not widely used and the idea of scrubbing is an emerging technology. The use of filters and water, however, are well known techniques.

Unit cost estimate (Set up)

Relatively high

Unit cost estimate (Maintenance and Operation)

Relatively low maintenance and operational cost

Comment of durability/life cycle

Filters, and scrubber solution would need replacing regularly.

Practicality

Medium practicality as is utilising existing space under roads.

Political appeal

High political appeal as is an innovative feature which could dramatically reduce air pollution impacts.

Public acceptability

High public acceptability as would not be visible, there would be no disruption to road networks as most of the work would occur underground and could dramatically improve air quality.

Other comments

Practicality of adopting sewer systems for this "dual purpose" is unproven. Further investigation would also be needed into the practicality of capturing the pollutants at below ground level. Concerns about potential impacts on the water environment need consideration.

Potential for IPL (High/Medium/Low)

Medium

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
4	Housset Fernand Gilbert	

Title of Patent

Process for cleaning the polluted air of urban areas

Country	Language	Date	Superseeded	Fees Paid? Y/N
France	French	1996	Y (FR2748221	N (Lapsed)

Description of patent

This appears to be similar to the patent filed by Chester L Foster 1975 ‘Method and apparatus for treating polluted air along auto traffic arteries’. This uses the existing water sewerage system as a means of removing polluted air away from the roadside, treating it using a variety of chemical and physical processes, then ventilating the exhaust away from the roadside, possibly in a parkland.

Which pollutants are being addressed?

All pollutant gases and particulates

Maturity of technology

The principle of using the water drainage system to remove polluted air is not presently used to our knowledge but the subsequent air treatment processes are. This could infringe the Foster 1975 patent depending on the date of the patent and country of applicability

Unit cost estimate (Set up)

Relatively high

Unit cost estimate (Maintenance and Operation)

Relatively low maintenance and operational cost

Comment of durability/life cycle

Filters and scrubber solution would need replacing regularly.

Practicality

Medium practicality as is utilising existing space and infrastructure under roads.

Political appeal

High political appeal as is an innovative feature which could dramatically reduce air pollution impacts.

Public acceptability

High public acceptability as would not be visible, there would be no disruption to road networks as most of the work would occur underground and could dramatically improve air quality.

Other comments

Practicality of adopting sewer systems for this "dual purpose" is unproven. Further investigation would also be needed into the practicality of capturing the pollutants at below ground level. Concerns about potential impacts on the water environment need consideration.

Potential for IPL (High/Medium/Low)

Medium

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
3	Geochto KK Isumi Intec KK	

Title of Patent

Exhaust gas and dust eliminator in tunnel

Country	Language	Date	Superseeded	Fees Paid? Y/N
Japan	Eng/Japanese	1998		

Description of patent

An air cleaner which sucks in contaminated air, sprays water into the airstream and generates negative ions. The droplets are then separated from the air (possibly by a centrifuge) before the clean air is returned

Which pollutants are being addressed?

Particulate and possibly some gaseous pollutants

Maturity of technology

This employs 2 techniques which are already in use for industrial processes and cleansing air.

Unit cost estimate (Set up)

Probably relatively cheap compared to other pollution removal methods

Unit cost estimate (Maintenance and Operation)

Comment of durability/life cycle

Unclear

Practicality

This appears to be similar to an industrial wet water scrubber with the additional introduction of a negative charge to the airstream. It is unclear if something as simple as this would work effectively with the low concentrations and the smaller aerodynamic size of particulate found in a road tunnel. It is also unclear what the purpose of introducing the negative charge is. Ionisers can be used to give particles a negative charge so they can be attracted to an cathode of opposite charge, but this is not mentioned. Providing air with a negative charge can create Ozone which can lead to the formation of NO2 and is a pollutant in its own right.

Political appeal

Unclear

Public acceptability

Unclear

Other comments

It is unclear as to how effective this system would work

Potential for IPL (High/Medium/Low)

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
3	Aiken Kogyo KK	

Title of Patent

Non-powered air cleaner in tunnel

Country	Language	Date	Superseeded	Fees Paid? Y/N
Japan	Eng/Japanese	1998		

Description of patent

Vehicles passing through the tunnel cause a forced airflow through the tunnel due to a 'piston effect'. The force of air powers a turbine which is attached to a pump or scoop which forces water into or through a device which exposes the water to an airflow. The patent abstract fails to describe how this device works. However, mention of 'high surface area', 'a water film' and 'dust' implies that the water is either dripped or spayed into the airflow to remove coarse particulate matter in the form of a 'scrubber'. The water also appears to be pumped from an underground source to a reservoir at the level of the tunnel possibly using the same power source as described above.

Which pollutants are being addressed?

Mainly coarse particulates

Maturity of technology

This technology appears to consist of a particulate scrubber system powered by the force of the airflow from the movement of vehicles passing through the tunnel. Scrubbing technology is mature or at least covered by other patents. Some other patents use vehicle induced airflow for the purposes of pumping air through air treatment devices. The concept of pumping water from the induced vehicle airflow is probably novel, but only because it has few benefits.

Unit cost estimate (Set up)

Relatively expensive to install

Unit cost estimate (Maintenance and Operation)

Using vehicle induced airflow could avoid the use of powered fans thereby reducing some of the running costs.

Comment of durability/life cycle

Using vehicle induced airflow for driving a pumping mechanism could avoid the use of powered water pumps, however it is unlikely that this would have substantial benefits.

Practicality

Using vehicle induced airflow to power an air purification system may have some merits. However this device appears to focus on describing how this principle could be used to pump water using a turbine, gearing mechanism and 'scoops'. This system may be unnecessary, archaic in detail or overcomplicated relative to conventional liquid pumping systems which should have a low power requirement in relation to the other processes. The method of purifying the air is only vaguely described in the patent, but it doesn't appear to include any details using modern cleaning or scrubbing concepts.

Political appeal

Unlikely to have any political appeal

Public acceptability

Unlikely to have any public appeal

Other comments

This patent may be poorly translated, however it appears to be inadequately researched.

Potential for IPL (High/Medium/Low)

Low

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
3	Vanco Dimitrov	

Title of Patent

System for absorption of the exhaust gases in a tunnel for road traffic

Country	Language	Date	Superseeded	Fees Paid? Y/N
??	English	1997	N	Y

Description of patent

An absorption system for vehicle exhaust gases in tunnels. This system primarily consists of sprinklers, absorbers, side panels and roof panels. The exhaust gases are sprayed with an absorption liquid by the sprinklers to provide a protective film on the gases (decreasing their expansion in the upper areas of the tunnel, absorbing hard particles, and cooling the gases). The lowest part of the air in the tunnel is the most polluted part. This part is directed to the side absorbers via partitions. This air then passes through the absorbers into the side wall of the tunnel and then through the plastic panels. It then mixes with the other air in the tunnel and is passed among the roof panels towards the roof absorber. The roof absorber provides the final purification system.

Which pollutants are being addressed?

Vehicle exhaust emissions

Maturity of technology

This is an emerging technology with regards to the treatment of air in tunnels, and would require further exploration. This patent does not mention specific absorber types but activated carbon, for example, could be used.

Unit cost estimate (Set up)

Potentially expensive

Unit cost estimate (Maintenance and Operation)

Regular costs would involve replacement of absorbers, and absorption liquid

Comment of durability/life cycle

Absorbers and absorption liquid would require regular replacement

Practicality

Medium practicality as would help reduce air pollution impacts but may cause some disruption to the road network during installation

Political appeal

Potentially high political appeal and would be a visible feature. It is an innovative and has the potential to significantly improve air quality in tunnels

Public acceptability

Medium public acceptability as may cause some disruption to the road network during installation

Other comments

A complex proposed system with unproven technology - i.e. the protective film on the gases. Practicalities regarding the use of liquids and skidding/other implications.

Potential for IPL (High/Medium/Low)

Low

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
2	Phillip A Lincoln	

Title of Patent

Air treatment method and apparatus for reduction of VOCS NOX and CO in an air stream

Country	Language	Date	Superseeded	Fees Paid? Y/N
USA	English	1999	N	N (Expired 2003)

Description of patent

Air treatment method and apparatus for reduction of VOCs, NOC and CO in an airstream

Which pollutants are being addressed?

VOCs, NOC and CO

Maturity of technology

Some of the treatment processes are similar to those used in commercial systems employing UV light and oxidants. The precise mechanism is probably unique, and relies on hydroxyls and peroxides rather than ozone as the oxidant

Unit cost estimate (Set up)

The system is relatively complex and would probably entailed substantial cost, although it is difficult to compare with conventional systems without a detailed study.

Unit cost estimate (Maintenance and Operation)

Comment of durability/life cycle

Patent claims that operating and maintenance costs are reduced relative to competitive systems.

Practicality

The system is designed towards treating exhaust stacks of industrial plants than the more dilute streams and larger flows associated with road tunnels and urban air pollution.

Political appeal

Possibly not oriented towards tunnels and air pollution and therefore less political appeal than patents which are.

Public acceptability

Acceptable to public providing it does not incur greater costs.

Other comments

A detailed and well researched patent which may be more applicable for concentrated exhaust flows found in industrial stacks rather than encountered in tunnel or urban air. For example the invention quotes an example flow of 20000 cfm (9.3 m3/s) whereas Patent 'tunnel exhaust air treatment' WO 2004/022918 A1 quotes (470 m3/s) ventilation rate for a 3km tunnel.

Potential for IPL (High/Medium/Low)

Low

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
3	Hitachi Shipbuilding Eng Co	

Title of Patent

Device for cleaning ventilation gas of road tunnel or the like

Country	Language	Date	Superseeded	Fees Paid? Y/N
Japan	Eng/Japanese	1991		

Description of patent

This appears to consist of a rotary adsorptive denitrator to reduce NOx from the ventilation air of a road tunnel. The rotary unit consists of a NOx absorbing zone, unregenerated absorbent preheating zone, a regenerating zone, and an regenerated absorbent cooling zone. Ammonia is recirculated through the system and a denitrating reactor is also used before the cleaned air is released to the atmosphere. Although it is unclear from the abstract, this patent may be proposing an absorbing/desorbing unit to concentrate the NOx for subsequent passage through a selective reduction catalyst

Which pollutants are being addressed?

NOx

Maturity of technology

Unclear due to insufficient data.

Unit cost estimate (Set up)

Unclear due to insufficient data.

Unit cost estimate (Maintenance and Operation)

Comment of durability/life cycle

Unclear due to insufficient data.

Practicality

Unclear due to insufficient data.

Political appeal

Unclear due to insufficient data.

Public acceptability

Unclear due to insufficient data.

Other comments

Diagram needs enlarging and more text may be needed for a full interpretation. It appears the rotating unit simply absorbs and desorbs the NOx were the actual conversion of NOx to O2 and N2 takes place in the denitrating reactor. The use of Ammonia implies this denitrating reactor operates by a selective catalytic reaction principle.

Potential for IPL (High/Medium/Low)

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
2	Hitachi Shipbuilding Eng Co	

Title of Patent

Remove low-concentration NOX and SOX in an exhaust gas for ventilation

Country	Language	Date	Superseeded	Fees Paid? Y/N
Japan	Eng/Japanese	1993		

Description of patent

A system involving the removal of low concentrations on NOx and SOx simultaneously. This is done by desulphurising vehicle emissions in a wet state in a moisture adjustment column in the upstream of a rotary absorption denitrification device, The emissions are denitrified in the rotary absorption denitrification device.

Which pollutants are being addressed?

Low concentrations of NOx and SOx

Maturity of technology

As of 2004, the operational use of denitrification technology in road tunnels has been limited to a system supplied by Alstom in the Laerdal Tunnel, Norway. The performance of this system has been difficult to assess as the traffic and pollutant levels in this tunnel are relatively low. The Japanese systems developed by Matsushita and Kawasaki, and the German system developed by FILTRONtec have been successfully demonstrated but have not been applied in a commercial sense as yet. (TRL Report). Desulphurisation is also an emerging technology in relation to use in tunnels.

Unit cost estimate (Set up)

Potentially expensive

Unit cost estimate (Maintenance and Operation)

Relatively inexpensive to maintain and operate

Comment of durability/life cycle

Practicality

Medium practicality

Political appeal

High political appeal as is an innovative device and would help to reduce air quality problems in and around road tunnels

Public acceptability

High public acceptability as would help to improve air quality in and around tunnels, and would not be visually intrusive

Other comments

Chemical processes of desulphurisation unclear. Relatively complex and expensive to operate. Sox less of a critical problem currently in road environments.

Potential for IPL (High/Medium/Low)

Medium

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
3	Arnold Scheel	

Title of Patent

Air Cleaning System

Country	Language	Date	Superseeded	Fees Paid? Y/N
Germany	German	1998	N	N

Description of patent

An air cleaning system which comprises of several cleaning devices spaced along a tunnel. One embodiment uses longitudinal flow, another a single cleaning system, another transverse flow with cleaning units arranged above and below the ceiling and/or the floor of a tunnel. The quantity of ventilation airflow is kept low by using several cleaning devices and recirculating it. The cleaning devices consist of 'oxidation states' (possibly catalysts), dust filters, and an activated carbon filter.

Which pollutants are being addressed?

Hydrocarbons, NO2, CO, and particulates.

Maturity of technology

Variation on present systems

Unit cost estimate (Set up)

The patent claims that the unit cost are much lower than other systems.

Unit cost estimate (Maintenance and Operation)

The patent claims that the maintenance and operating costs are much lower than other systems. This is partly due to the ability to clean different zones in proportion to their requirement.

Comment of durability/life cycle

Filters and absorbents would require periodic renewal

Practicality

The system relies on the cleaning of air within the tunnel itself rather than ventilating it out, therefore the cleaning processes would have to be relatively efficient, reliable and durable. There is no reason why the particular cleaning systems could not be used in a similar way outside tunnels in highly polluted locations. The patent seems to be focussed on the concept of recirculating clean air within the tunnel.

Political appeal

Low costs would add to its political appeal, possibly Medium appeal

Public acceptability

Medium acceptability

Other comments

Probably more applicable to tunnels and enclosed spaces than open areas

Potential for IPL (High/Medium/Low)

Medium

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
3	Hitachi Ltd	

Title of Patent

Method for purifying nitrogen oxide-containing gas and apparatus

Country	Language	Date	Superseeded	Fees Paid? Y/N
Japan	Eng/Japanese	1999		

Description of patent

A porous body is 'disposed' on the inner surface of the tunnel wall. This is washed with a liquid to dissolve and wash out NOx ions. The liquid is collected at the bottom of the tunnel in a recovery tank, sent to a solid/liquid separation tank, then an electro-dialysis cell where a concentration of NOx ions in liquid solution is produced. This solution is then sent to a de-nitrification unit where bacterial process reduces the NO2 to N2 and O2.

Which pollutants are being addressed?

NO2

Maturity of technology

Some of the processes such as bacterial denitrification are well known. However the whole set of processes appears to be unique.

Unit cost estimate (Set up)

A large number of processes are involved, however the size (and possibly cost) of these are minimised be concentrating NO2 in a liquid

Unit cost estimate (Maintenance and Operation)

Operating costs may be high

Comment of durability/life cycle

Practicality

Some of the processes are established, however, the nature of the porous body and the washing technique is not clear. It would be worth further investigation

Political appeal

High if it works

Public acceptability

High if it works

Other comments

Difficult to judge from the summary alone.

Potential for IPL (High/Medium/Low)

Medium

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
3	Kensetsu Kikaku Consultant KK	

Title of Patent

Means and equipment for purifying ventilation gas of tunnel

Country	Language	Date	Superseeded	Fees Paid? Y/N
Japan	Eng/Japanese	2000		

Description of patent

The patent describes a system to remove harmful gases and particulates from polluted air in tunnels. A ventilation tunnel is created and the polluted gas is passed along it via a ventilation port. This gas is then passed through purifying equipment containing an absorbing agent consisting of an alkali substance.

Which pollutants are being addressed?

Nitrogen oxides, sulphur dioxides, particulate matter.

Maturity of technology

This is an emerging technology with regards to the treatment of air in tunnels

Unit cost estimate (Set up)

Potentially expensive

Unit cost estimate (Maintenance and Operation)

Energy costs and regular costs involving the replacement of the absorbing agent

Comment of durability/life cycle

Regular replacement of the absorbing agent

Practicality

Medium practicality

Political appeal

Medium political appeal as it would help improve air quality

Public acceptability

High public acceptability as would help to reduce air quality impacts but would not be visually intrusive

Other comments

Does not appear to be particularly novel and insufficient detail to conclude whether the benefits warrant operational costs.

Potential for IPL (High/Medium/Low)

Medium

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
2	Hyder Consulting PTY Ltd	

Title of Patent

Tunnel exhaust air treatment

Country	Language	Date	Superseeded	Fees Paid? Y/N
Australia	English	2004	N	Y

Description of patent

Tunnel exhaust air treatment: method for reducing pollutants in vehicle tunnel exhaust stack by passing the polluted air through a filter + gas turbine or combustion chamber/and a selective catalytic reduction (SCR) catalyst before exhausting to atmosphere

Which pollutants are being addressed?

Vehicle emissions in particular carbon monoxide, nitrogen oxides, hydrocarbons and particulates.

Maturity of technology

Using SCRs in conjunction with gas turbines mature, http://www.tenviro.com/SCR.htm Method as used immature.

Unit cost estimate (Set up)

Probably little additional unit cost if a power generation system was going to be used anyway and the space was available. Ongoing cost of ammonia may be significant

Unit cost estimate (Maintenance and Operation)

Comment of durability/life cycle

SCR catalysts are widely used to control emissions in stationary power plants. Patent may be more similar to this situation than automotive applications for which long term durability is unproven.

Practicality

Use of a gas turbine may increase local air pollution unless the catalyst is highly effective, further proof or research required, overall benefit unclear.

Political appeal

Some political appeal in reducing local air pollution if it works, however having power plant nearby may be adversely appealing.

Public acceptability

Evidence suggests that the device may be useful for obtaining initial public acceptance of a new tunnel, but perhaps is of less benefit once the tunnel is actually installed. http://en.wikipedia.org/wiki/Cross_City_Tunnel. Public acceptance of a power plant complicates the issue.

Other comments

The cost of installing the invention, above that of a conventional power plant, would need to be compared with obvious alternatives such as using multiple or higher stacks to distribute pollution from the tunnel. Overall photochemical pollution in tunnel should be less than an equivalent stretch of open road, so the issue is a highly localised one from the exhaust stack. The device requires a pre filter prior to entering the gas turbine or combustion chamber. Dust filtration systems for tunnels have been found to be only 20% effective and have been discontinued (Willoughby 2004)

Potential for IPL (High/Medium/Low)

High

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
3	Emil Johannes Wieser-Linhart	

Title of Patent

Construction built along a road for noise and fumes reduction

Country	Language	Date	Superseeded	Fees Paid? Y/N
Germany	German	2003	N	N

Description of patent

This system involves building a tunnel (consists of a roof and walls held together by release mountings) over the road surface to reduce noise and air quality impacts. The road cover includes and exhaust gas extractor attached to a cleaning unit. The cleaning unit cleans the air by using a filter for solids, and a biological cleaning stage for CO, NOx and HCx. The roof has acoustic dampers at its base to help to absorb the road noise.

Which pollutants are being addressed?

Vehicle emissions in particular carbon monoxide, nitrogen oxides, hydrocarbons and particulates.

Maturity of technology

Not very mature

Unit cost estimate (Set up)

May be less expensive than re-routing roads

Unit cost estimate (Maintenance and Operation)

Filters, and biological cleaning agents would need replacing regularly.

Comment of durability/life cycle

Filters, and biological cleaning agents would need replacing regularly with waste management implications.

Practicality

Medium practicality as would help to solve air quality and noise problems on existing road systems. Patent claims it could potentially reduce the need for the rerouting of roads.

Political appeal

High political appeal as has the WOW factor. It would be innovative and would reduce air quality problems, and noise impacts.

Public acceptability

Medium public acceptability as would improve air quality, and noise impacts. It would, however, have a visible impact on the landscape and could be disruptive during construction and may cause community severance.

Other comments

Details of the biological cleaning process and water requirements unclear and would need further consideration. Maintenance and cleaning implications (including road closures).

Potential for IPL (High/Medium/Low)

High

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
3	Fujita Corp	

Title of Patent

Cleaning method of polluted air in tunnel

Country	Language	Date	Superseeded	Fees Paid? Y/N
Japan	Eng/Japanese	1999		

Description of patent

Tunnel air is passed into an upper cavity situated along the length of the tunnel. The air passes through a soil bed and back into the tunnel cavity. (this presumably consumes, converts or otherwise removes some of the pollutants through biological action, although this isn't stated in the summary)

Which pollutants are being addressed?

NOx, but this could work with other pollutants

Maturity of technology

Bioactive soils have been used for removing pollutants from contaminated air (see practicality below)

Unit cost estimate (Set up)

Less expensive that other filtration equipment but energy needed to force air through soils.

Unit cost estimate (Maintenance and Operation)

Comment of durability/life cycle

This system is potentially renewable.

Practicality

This appears to be a method of Bio-filtration in which contaminated air is passed through soil (presumably containing micro-organisms capable of consuming, converting or otherwise removing some of the NOx present). Bio-filtration offers a potentially sustainable and cost effective approach to the treatment of road tunnel emissions. It is unclear, however, whether the system designed in this patent would be able to cope with the high levels of emissions associated with road tunnels.

Political appeal

High since this reduces overall pollution levels as well as ventilating the tunnel, although the ventilation flow rate could be compromised

Public acceptability

High since this involves a sustainable process

Other comments

Contamination of the soil needs to be considered. Questions over the quantity of soil need to treat large volumes of air pollutants.

Potential for IPL (High/Medium/Low)

High

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
2	Fujita Corp	

Title of Patent

Cleaning of polluted air in tunnel

Country	Language	Date	Superseeded	Fees Paid? Y/N
Japan	Eng/Japanese	2000		

Description of patent

A system to clean polluted air in tunnels by sucking the air out of the tunnel and allowing it to pass through a layer of soil before allowing it into the atmosphere

Which pollutants are being addressed?

Vehicle emissions

Maturity of technology

Not very mature

Unit cost estimate (Set up)

Less expensive that other filtration equipment but energy needed to force air through soils.

Unit cost estimate (Maintenance and Operation)

Soil may need treating

Comment of durability/life cycle

Soil may need treating

Practicality

Medium practicality as would mean tunnels have to be constructed in a certain manner

Political appeal

Medium political appeal as would help filter air in a fairly cheap way

Public acceptability

High public acceptability as would improve air quality

Other comments

Contamination of the soil needs to be considered. Questions over the quantity of soil need to treat large volumes of air pollutants.

Potential for IPL (High/Medium/Low)

High

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
2	Hitachi Shipbuilding Eng Co	

Title of Patent

Method for purifying ventilation gas in road tunnel

Country	Language	Date	Superseeded	Fees Paid? Y/N
Japan	Eng/Japanese	1989		

Description of patent

Contaminated ventilation air extracted from a road tunnel is introduced to a moisture absorbing medium such as silica gel. The air is then treated with a zeolite based adsorbent containing the oxide of a metal to remove NOx. Part of the treated gas is then moved to a preheating or cooling facility to dry the silica gel. The adsorbent is regenerated by passing heated air through it.

Which pollutants are being addressed?

NOx

Maturity of technology

Zeolite based adsorbents have been used to treat exhaust gas, the entire process is unique as far as it is unknown

Unit cost estimate (Set up)

See practicality

Unit cost estimate (Maintenance and Operation)

Comment of durability/life cycle

Not enough data

Practicality

The individual processes are well known, however it is unknown if they could be used in combination to treat large volumes of air economically. The preheating and processes may lead to the release of significant CO2 emissions. This must be considered also.

Political appeal

Medium

Public acceptability

Medium

Other comments

Potential for IPL (High/Medium/Low)

Medium

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
3	Hitachi Ltd	

Title of Patent

Tunnel air purifying device

Country	Language	Date	Superseeded	Fees Paid? Y/N
Japan	Eng/Japanese	1996		

Description of patent

A system comprising of light treatment to reduce concentrations of noxious chemical material. The system works by the use of a light collector, an optical fibre, light projectors and photo catalyst sheets. The sunlight is collected in the light collector on outside of the tunnel and is fed through the tunnel by an optical fibre. The light is then radiated to the photo catalyst sheets which are stuck from the tunnel wall face to the ceiling.

Which pollutants are being addressed?

Noxious gases

Maturity of technology

Not very mature

Unit cost estimate (Set up)

Expensive but would negate the impact of having to use more energy

Unit cost estimate (Maintenance and Operation)

Fairly expensive

Comment of durability/life cycle

Practicality

Medium practicality

Political appeal

High political appeal as would be innovative

Public acceptability

High public acceptability

Other comments

Unproven cost effectiveness and practicalities of technologies (fibre optics). Wash treatments or alternatives are not considered.

Potential for IPL (High/Medium/Low)

Medium

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
3	Sekisui Jushi KK: Agency Ind Science Tech	

Title of Patent

Apparatus for cleaning air in tunnel and tunnel interior panel used

Country	Language	Date	Superseeded	Fees Paid? Y/N
Japan	Eng/Japanese	1997		

Description of patent

Titanium oxide is pasted on the tunnel interior. Ultra violet (UV) lamps irradiate this surface allowing NO, SO and tyre particulate emissions produced by traffic in the tunnel to oxidize to an acid form. A washing device removes the acid from the side walls of the tunnel.

Which pollutants are being addressed?

NO, SO and Particulate

Maturity of technology

The use of Titanium oxide coatings for outside surfaces using Solar UV light have been trialled in Milan and Westminster London

Unit cost estimate (Set up)

Trials coating paving slabs with Titanium oxide suggest that the unit cost is approximately twice that of conventional pre-cast concrete paving.

Unit cost estimate (Maintenance and Operation)

Comment of durability/life cycle

Practicality

Field trials in Milan in 2002, achieved a 60% reduction in the concentration of nitrogen oxides at street level.1 The energy use required to achieve the required UV irradiation in the tunnel would have to be considered. UV light which would normally be absent in tunnels promotes photochemical reactions which lead to secondary pollutants, so it unclear if the method would produce a net benefit.

Political appeal

High, providing costs are not prohibitive

Public acceptability

High

Other comments

Titanium oxide acts as a photo-catalyst and may also be useful in converting NO2 to a nitrate form.

Potential for IPL (High/Medium/Low)

Medium

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
3	Sengbusch Lutz	Schnick & Fiebig

Title of Patent

Method and device for cleaning exhaust air by separating particles and pollutant gases

Country	Language	Date	Superseeded	Fees Paid? Y/N
Germany	German	1997	N	Y

Description of patent

A device for cleaning air masses with relatively low levels of contamination. In one version of the design, air is forced through various filter and cleaning technologies by the orientation of inlet and outlet ducts and the pressure differential induced by vehicle movement. The spacing of these ducts in relation to the length of vehicle is thought to be important. The cleaning technologies incorporate a course filter, controlled electrostatic filter, mechanical filter with selectable washer, biofilter with activated carbon, and a selectable ventilator. The cleaning units appear to be incorporated alongside the road or tunnel. A variant on this design uses forced ventilation to assist the vehicle piston effect. It also appears as if the filter unit can detect a rapid rise in particulate concentrations thereby sensing a fire.

Which pollutants are being addressed?

All air pollutants

Maturity of technology

Elements of the idea have been used in other designs

Unit cost estimate (Set up)

The unit cost could be high due to the use of many multiple cleaning systems. In one variant the power use (and therefore running costs) may be reduced due to the use of vehicle induced ventilation

Unit cost estimate (Maintenance and Operation)

The unit cost could be high due to the use of many multiple cleaning systems. In one variant the power use (and therefore running costs) may be reduced due to the use of vehicle induced ventilation

Comment of durability/life cycle

The patent claims that the electrostatic filters life is extended by controlling the ionisation current in accordance with the level of particulate contamination in the tunnel

Practicality

The device would require the treatment technologies to be incorporated all along the tunnel, this may require a tunnel with an overall larger diameter than alternative designs to accommodate the various systems

Political appeal

The use of vehicular ventilation may have the additional benefit of a reduced power requirement and therefore greenhouse gases due to the reduction in power required to ventilate the system (although a rise in vehicle aerodynamic friction could compensate for this).

Public acceptability

Public may approve if the system is effective at reducing pollution

Other comments

This appears to incorporate a large number of air cleaning technologies which is thought to be more effective and economic than focussing on a few of them.

Potential for IPL (High/Medium/Low)

Medium

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
3	Ursula Lutzkat	

Title of Patent

Light-permeable noise and environmental protection cover for motor ways etc. consists of tunnels of recycled waste materials, with solar collectors, exhaust filters, etc.

Country	Language	Date	Superseeded	Fees Paid? Y/N
Germany	German	1998	N	N

Description of patent

This system involves covering a road in a tunnel type structure that is light permeable, sound absorbent and made from recycled materials. The cover has solar collectors and integral filter systems for exhaust fumes. This system can be coupled to energy generating biological waste recycling plants to generate energy, heat and fertiliser. In addition, the tunnel cover can be covered by a bridge for cyclists, pedestrians and animals.

Which pollutants are being addressed?

Potentially all vehicle emissions

Maturity of technology

Not very mature

Unit cost estimate (Set up)

May be less expensive than re-routing roads

Unit cost estimate (Maintenance and Operation)

Filters would need replacing regularly.

Comment of durability/life cycle

Filters would need replacing regularly with waste management implications.

Practicality

Medium practicality as would help to solve air quality and noise problems on existing road systems. In addition, if a biological waste recycling plants was built local heat and energy could be provided.

Political appeal

Potentially high political appeal. It would be innovative and would reduce air quality problems, and noise impacts.

Public acceptability

Medium public acceptability as would improve air quality, and noise impacts. It would, however, have a visible impact on the landscape and could be disruptive during construction. If the system was built in conjunction with a biological waste recycling plants local heat and power could be provided.

Other comments

Maintenance and cleaning implications (including road closures).

Potential for IPL (High/Medium/Low)

High

Category	Name of Applicant	Company Name (This will sometimes be the same as the applicant)
2	Shigaya Nobushige	

Title of Patent

Cleaning device to be used in discharging contaminated air in tunnel

Country	Language	Date	Superseeded	Fees Paid? Y/N
Japan	Eng/Japanese	2001		

Description of patent

A system utilising titanium oxide to clean NOx.

Which pollutants are being addressed?

Nitrogen oxides

Maturity of technology

The use of photo-catalysts is a relatively new technology. Titanium oxide is one of these catalysts , and combined with UV can produce strong oxidising reactions.

Unit cost estimate (Set up)

Potentially expensive

Unit cost estimate (Maintenance and Operation)

Potentially inexpensive

Comment of durability/life cycle

Practicality

Political appeal

Public acceptability

Other comments

Potential for IPL (High/Medium/Low)

Medium