A guide for fleet operators on retrofit diesel abatement for particulate matter. Includes information on technical options, benefits and costs.
About The Black Carbon Campaign

The Black Carbon Campaign is raising awareness of the need to reduce black carbon emissions to help achieve rapid climate change mitigation and slow the rate of Arctic melting. It is a partnership between the NGOs ClientEarth and Environmental Protection UK, and forms part of the wider European Soot Free for the Climate alliance.

More information about the Campaign is available at www.clientearth.org

About This Guidance

This guide provides basic information on the reduction of particulate matter emissions from diesel vehicles and equipment (‘retrofit exhaust abatement’). It sets out why operators of diesel vehicles and equipment may want to reduce particulate emissions and provides information on the technical options available for emission reduction.

This guide covers ‘diesel vehicles and equipment’, which includes any mobile item with a diesel engine. For example, emissions from lorries, buses, cars, railway locomotives, inland ships, agricultural machinery and construction equipment can all be addressed.

This guide is intended to be a starting point for those looking at black carbon and particulate matter abatement rather than a detailed guide. Readers who require more information are provided with links to sources of further guidance.

Credits

The principal editor for this guidance was the independent consultant Ed Dearnley (info@dearnley.org.uk).

The Black Carbon Campaign thanks the Environmental Industries Commission, Johnson Matthey and Eminox for providing case studies and comments on the final text.

The discussion of commercially available products within this guidance does not constitute endorsement of any kind. This document represents guidance from the Black Carbon Campaign, and does not necessarily reflect policy within the organisations of those who have contributed to, or were consulted on, its development. Information relating to time relevant items was correct at the time of production.
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Section 1

Summary
All combustion engines and appliances produce exhaust gases. The biggest components of exhaust gas are generally water vapour and carbon dioxide, which are harmless at a local level. But they also contain substances that are damaging to our health. In heavily trafficked areas such as city centres concentrations of these air pollutants can build to levels that have severe impacts on the health of people who live and work there.

One of the most harmful exhaust pollutants is particulate matter – tiny airborne particles. Particulate matter is classified according to the maximum size of the particles. ‘PM\textsubscript{10}’ refers to all particles under 10 micrometers in diameter (0.001 mm), whilst ‘PM\textsubscript{2.5}’ refers to all particles under 2.5 micrometers in diameter (0.00025 mm).

A significant proportion of particulate matter is made up of black carbon which in addition to its health impact also affects our climate. The mechanism for black carbon’s climate impact is quite simple: as it is black it absorbs heat from the sun. The impact is particularly pronounced when black carbon settles on snow, as it darkens the surface and reduces the amount of sunlight reflected. This can ultimately cause the snow and ice to melt.

In the most polluted locations (such as city centres) diesel vehicles and equipment are usually the main source of particulate pollution/black carbon. Other sources of particulate matter and black carbon include the combustion of solid fuels (coal and wood), construction activity and industrial combustion.

To achieve very low particulate matter emissions a device known as a diesel particulate filter (DPF) is generally needed. These devices filter out the particulate matter before it is emitted into the air, trapping it within the filter where it is burnt off in a process known as ‘regeneration’. DPFs can be fitted to almost all types of diesel vehicles and equipment.

Most new diesel vehicles are now required to have a factory fitted DPF due to strict emission regulations set by the European Union, however this is a relatively recent development. The majority of diesel vehicles and equipment currently in use in the UK therefore do not have a DPF fitted. Older diesel vehicles and equipment can, however, be fitted with an aftermarket DPF in a process known as ‘retrofit’. This can dramatically reduce both particulate matter and black carbon emissions. This established technology has already been proven in upgrading thousands of older vehicles to today’s low particulate matter emissions standards.

Due to the undesirable impacts of particulate matter emissions there are a number of ‘carrot and stick’ measures to encourage operators of diesel vehicles and equipment to fit DPFs and other exhaust abatement equipment.

For road vehicles ‘Reduced Pollution Certificates’ are available for owners of older vehicles who add retrofit exhaust abatement equipment such as diesel particulate filters. Vehicles with these certificates are eligible for reduced Vehicle Excise Duty (road tax). Road vehicles may also be affected by Low Emission Zones (LEZs), areas where access is restricted to vehicles that meet a certain emission standard. Vehicles entering these areas that don’t meet the emission requirements of the zone may be subject to a large fine.

Construction equipment may also be required to meet certain emission standards as part of local authority planning conditions attached to the development they are being used to construct. These conditions usually mean the developers needs to ensure that contractors use modern filtered equipment, or fit older equipment with retrofit exhaust abatement equipment.

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Section 2
Emission Standards

- Guide to emission standards
- Introducing aftermarket (retrofit) exhaust abatement
- Identifying vehicles or equipment that already have a diesel particulate filter
Section 2
Emission Standards

What are Emission Standards?

2.1 All vehicles and equipment that use a diesel or petrol engine will have been constructed to meet an emission standard. The standard sets maximum levels of several air pollutants that can be emitted from the vehicle or equipment’s exhaust. These pollutants include particulate matter and several other common air pollutants, such as oxides of nitrogen (NOx), hydrocarbons (HC) and carbon monoxide (CO). In the UK emission standards are normally set by the European Union, which has introduced them to improve poor air quality in our towns and cities. It is illegal to sell vehicles and equipment in the UK that do not meet any relevant European emissions standard.

2.2 Emission standards for road vehicles are known as ‘Euro standards’. Their key features are:

- There are separate standards for light vehicles (cars and vans) and heavy vehicles (buses and HGVs)
- They advance sequentially from Euro 1 (from 1992) to Euro 6 (2014) with increasingly tight requirements. Euro standards for heavy vehicles are usually written with a roman numeral (e.g. Euro IV) to distinguish them from light vehicle standards (e.g. Euro 4)
- Light vehicle standards apply to the actual vehicle model (e.g. a VW Golf, Ford Mondeo, etc). Heavy vehicle standards apply to the engine used in the vehicle: vehicles themselves are not tested individually

2.3 Emission standards for other diesel equipment are known as ‘Non-Road Mobile Machinery (NRMM) standards’. Their key features are:

- They advance from Stage 1 (1999) to Stage 4 (2014) with increasingly tight requirements. Stage 3 contains two sub stages (IIIA and IIIB)
- There are different standards for different sizes (power outputs) of engines
- There are separate standards for railway locomotives and inland water vessels

2.4 Vehicles and equipment compliant with a new emission standard usually begin to be released before the standard becomes mandatory. The emission standard that any particular vehicle or equipment was constructed to meet will be noted on its registration documents.

What Does Retrofit Exhaust Abatement Do?

2.5 Retrofit exhaust abatement aims to reduce the emissions from a vehicle or a piece of equipment. A retrofitted vehicle or piece of equipment will have emissions below the emission standard which it was originally constructed to meet, and will normally be tested to certify the fact that it meets a new, stricter emission standard. Retrofit can be used to reduce emissions of one or more pollutants. Whilst this guide focuses on reducing emissions of particulate matter, retrofit to reduce emissions of nitrogen oxides is also common.

2.6 Usually retrofit equipment is designed to make the vehicle/equipment meet a higher emission standard: for example a bus constructed to meet the Euro II emission standard could be retrofitted to meet the Euro IV or even Euro V standard for one or more pollutants. Retrofit equipment can be calibrated in order to best reduce emissions according to ‘real world’ use. For example if an urban bus is retrofitted the equipment can be optimised to reduce emissions most effectively in stop-start urban driving, whilst if an HGV used mainly on motorways was retrofitted the equipment can be optimised for high speed conditions.
Is My Vehicle or Equipment Already Fitted with a DPF?

2.7 A full DPF dramatically reduces particulate matter emissions. However, if a vehicle or piece of equipment is fitted with a DPF from new there is little benefit in fitting a new one. If you are considering fitting a DPF it is therefore important to know whether your vehicle or equipment already has a factory fitted filter.

2.8 Whilst manufacturers are free to use any technology to meet particulate matter emissions standards, in practice once the standard is tightened beyond a certain point a DPF becomes the only cost effective way of meeting it.

2.9 Table 1 opposite shows when DPFs became, in effect, mandatory for different types of newly manufactured vehicles and non road machinery. Vehicles and equipment purchased new in the years shown by the green bars will almost certainly be fitted with a DPF. Note that older vehicles and equipment may also be fitted with a particulate filter, as manufacturers often update models prior to the deadline set by new emission regulations.

2.10 If in doubt a mechanic will be able to inspect your equipment or vehicle to tell you if it is fitted with a DPF.

<table>
<thead>
<tr>
<th>Year</th>
<th>Cars and Light Vans</th>
<th>Buses and HGVs</th>
<th>NRMM 37-56kW</th>
<th>NRMM 56-75kW</th>
<th>NRMM 75-130kW</th>
<th>NRMM 130-560kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NOTES
- Cars and light vans require a filter to meet the Euro 5 standard (2011). Some Euro 4 cars were also often fitted with a filter, particularly larger vehicles
- Buses and HGVs (and other vehicles using heavy duty engines) will require a filter to meet the Euro VI standard
- Non-road mobile machinery requires a filter to meet the Stage IIIB standard. Equipment with an engine output less than 37 kW is currently only required to meet the weaker Stage IIIA standard and is unlikely to be fitted with a filter
Section 3

Why Retrofit?

- Financial, regulatory and corporate social responsibility drivers for retrofit exhaust abatement
- Health and climate impacts of particulate matter emissions
Section 3
Why Retrofit?

Why Would I Want to Install Retrofit Exhaust Abatement on my Vehicle or Equipment?

3.1 Operators of diesel vehicles and equipment may retrofit their vehicles for a number of reasons. However, generally the reasons behind an individual or a company retrofitting will fit into one of three categories:

• Because they have to (for example if a vehicle is used in an area where high emitting vehicles are banned)
• Because it is financially beneficial to do so
• For environmental reasons (for example Corporate Social Responsibility, agreements with local authorities, etc)

3.2 Policies and programmes that encourage the fitting of retrofit exhaust abatement are outlined below. Most of these apply to road vehicles - policies and programmes aimed at reducing emissions from non-road diesel equipment are less common at the time of writing.

Vehicles – Low Emission Zones

3.3 A Low Emission Zone (LEZ) is an area where only vehicles that meet certain emission standards are allowed to enter. Common features of LEZs are:

• They can apply to all vehicles or only certain vehicle types (e.g. large vehicles)
• They set a minimum Euro standard that a vehicle must meet for one or all pollutants covered by the standard
• The standards become increasingly strict over time

• Enforcement is carried via number plate recognition cameras or issuing window stickers to be checked by on-street traffic wardens
• Large fines are given to non-compliant vehicles caught in the LEZ

3.4 In the UK the largest and best known LEZ covers the whole of Greater London. It was established in 2008 and covers particulate matter emissions only at the time of writing. The LEZ initially only applied to HGVs and buses, but since 2012 heavier vans and minibuses have been included in the scheme. The London LEZ does not apply to cars and light vans. The current and historical standards for the LEZ are shown in Table 2 below.

<table>
<thead>
<tr>
<th></th>
<th>Phase 1 Feb 2008</th>
<th>Phase 2 Oct 2008</th>
<th>Phase 3 Jan 2012</th>
<th>Phase 4 Jan 2012</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lorries</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>over 12 tonnes</td>
<td>€uro III</td>
<td></td>
<td>€uro IV</td>
<td></td>
</tr>
<tr>
<td><strong>Lorries</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.5-12 tonnes</td>
<td>n/a</td>
<td>€uro III</td>
<td>€uro IV</td>
<td></td>
</tr>
<tr>
<td><strong>Minibuses</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>and vans</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>over 1.205 tonnes</td>
<td>n/a</td>
<td>n/a</td>
<td>€uro III</td>
<td></td>
</tr>
<tr>
<td><strong>Motor caravans</strong> and <strong>ambulances</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5-3.5 tonnes</td>
<td>n/a</td>
<td>n/a</td>
<td>€uro III</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: London LEZ standards (particulate matter only)
3.5 Other UK towns and cities including Reading, Oxford and Norwich have also introduced, or plan to introduce, LEZs. The vehicles and pollutants covered vary between the different LEZs.

3.6 Most LEZs allow vehicle operators to comply by retrofitting older vehicles to higher emission standards. For the purposes of the London LEZ a testing and certification system for particulate matter retrofit exhaust abatement has been established. Retrofitted vehicles can be tested, certified and added to a register that allows listed vehicles access to the London LEZ without penalty.

CASE STUDY
Complying with Low Emission Zones

When the London Low Emission Zone was introduced in 2008 many fleet operators needed to review their vehicle fleets in order to comply. If vehicles regularly driven in London did not comply fleet operators needed to work out whether to redeploy, retrofit or replace them. Since 2008 the LEZ standards have seen four phases of tightening, and again fleet operators have needed to work out the most cost effective way to comply.

TGM Group (formally Tellings Golden Miller) is a leading bus and coach operator specialising in aviation transport. TGM Group has a total fleet of 420 buses and coaches, 71 of which did not meet the new London LEZ Phase 4 requirements which came into effect in early 2012. Phase 4 introduces a tougher standard of Euro 4 for particulate matter (PM) for buses and coaches over 5 tonnes.

TGM considered a number of options to meet the new rules, including the re-deployment of its vehicles to other areas and the possibility of replacing the non-compliant vehicles altogether, before choosing retrofit as the most cost-effective solution. 71 buses, including models from Scania, Mercedes, Volvo and VDL, were upgraded using CRT® (Continuously Regenerating Trap) technology.

Buses and HGVs are not the only vehicles affected by the LEZ, and other public service vehicles also need to comply. SITA UK, a subsidiary of Suez Environment, is a leading recycling and resource management company. SITA UK identified 161 vehicles from their fleet of Scania, Daf, Dennis, Volvo and Mercedes refuse trucks to upgrade to meet the 2012 London LEZ Phase 4 requirements, which were again upgraded using CRT® (Continuously Regenerating Trap) technology.

Both companies used CRT systems from UK supplier Eminox. The Eminox CRT is a wall flow diesel particulate filter that achieves more than 90% particulate matter reduction and is approved to the new Transport for London (TfL) standards.

Vehicles – Reduced Pollution Certificates

3.7 Heavier vehicles registered in the UK prior to October 2006 may be able to obtain a Reduced Pollution Certificate (RPC) if they are adapted to meet a higher air quality standard than they were initially constructed to meet. Vehicles with an RPC are eligible for a reduction in Vehicle Excise Duty. Qualifying vehicles are HGVs (over 3.5 tonnes), buses and coaches.

3.8 In practice, to gain an RPC all pre-Euro IV diesel heavy vehicles must have been constructed or adapted to achieve a considerably higher standard of particulate emission than that required by the Euro standard in force at the time of manufacture. This usually means that a vehicle must either be fitted with a DPF or a new, low emission engine. A testing and certification regime is in place to award RPCs to eligible vehicles.

3.9 A vehicle can also gain a RPC if it is converted to run on petrol or gas (Liquid Petroleum Gas or Compressed Natural Gas). Vehicles registered in the UK before 1st October 2009 that are fitted with Euro V or Environmentally Enhanced Vehicle engines and nitrogen oxides control are also eligible for a RPC.
3.10 VED rates for HGVs and buses, both with and without RPCs, are show in Table 3 below (figures for 2011/12).

### Table 3: 2011/12 VED costs with and without a reduced pollution certificate

<table>
<thead>
<tr>
<th>Category</th>
<th>Standard Cost (year)</th>
<th>RPC Cost (year)</th>
<th>Saving (year)</th>
<th>HGVs</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>£165</td>
<td>£160</td>
<td>£5</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>£200</td>
<td>£160</td>
<td>£40</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>£450</td>
<td>£210</td>
<td>£240</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>£650</td>
<td>£280</td>
<td>£370</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>£1200</td>
<td>£700</td>
<td>£500</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>£1500</td>
<td>£1000</td>
<td>£500</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>£1850</td>
<td>£1350</td>
<td>£500</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of seats</th>
<th>Standard Cost (year)</th>
<th>RPC Cost (year)</th>
<th>Saving (year)</th>
<th>Buses</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 to 17</td>
<td>£165</td>
<td>£165</td>
<td>£0</td>
<td></td>
</tr>
<tr>
<td>18 to 36</td>
<td>£220</td>
<td>£165</td>
<td>£55</td>
<td></td>
</tr>
<tr>
<td>37 to 61</td>
<td>£330</td>
<td>£165</td>
<td>£165</td>
<td></td>
</tr>
<tr>
<td>62 and over</td>
<td>£500</td>
<td>£165</td>
<td>£335</td>
<td></td>
</tr>
</tbody>
</table>

3.11 Reduced Pollution Certificates are usually valid for 13 or 14 months. On request, the Vehicle and Operator Services Agency (VOSA) may provide an extension of up to 11 months for a first certificate, so that the test can be carried out at the same time as the vehicle’s annual check (MoT). At the time of writing a test cost £32 as a stand-alone test, and £19 if carried out with a vehicle’s annual check.

### Vehicles and Construction Equipment – Planning Conditions and Local Authority Agreements

3.12 Local authorities have air pollution responsibilities under the Local Air Quality Management regime and the (related) Local Transport Plan process. Local authorities have many different tools at their disposal to help improve air quality, but two of the most commonly used ones are their transport and local planning powers. Note that in areas with a two tier local authority structure (e.g. where there are district and county authorities) these two functions may sit in different local authorities.

3.13 Local authorities have their own in-house vehicle fleets, and have influence over other vehicle fleets where these are used to provide public services. Examples of the latter include waste collection vehicles, taxis and (where regulation or agreements exist) local buses. Several local authorities have used contracts and agreements to stipulate minimum emissions standards for public service vehicles, for example requiring buses or taxis to meet a minimum Euro standard or fit a DPF.

3.14 Local authorities often attach conditions to planning agreements to improve or offset the environmental impacts of new developments. Many local authorities have now introduced ‘Low Emission Strategies’ where planning conditions are used to reduce pollutant emissions from transport associated with new development, either by requiring developers to take action themselves or by contributing to a low emission fund. Under these strategies local authorities can require vehicles (or a percentage of vehicles) accessing major new developments to meet minimum emissions standards. Other common provisions include support for electric and other low (or zero) emission vehicles.

Why Retrofit?

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CASE STUDY
Low Emission Strategies in Greenwich

Low Emission Strategies use planning conditions to help mitigate the air quality and greenhouse gas impacts of new developments. Air quality assessment in the planning system is frequently ‘adversarial’, with developers and the planning authority arguing whether the impacts of a development are acceptable. Low Emission Strategies take a different approach by looking at mitigation actions that can be taken to allow a development to proceed.

Low Emission Strategies were pioneered by the London Borough of Greenwich and are now used by many local authorities all around the UK. Mitigation measures secured in Greenwich include:

• A temporary Low Emission Zone for the development and construction of the Warren development
• Emission based parking policies in the Greenwich Millennium Village
• Requirements for a new superstore to have 50% of delivery vehicles and 50% of home delivery vehicles associated with the store meeting the Euro 5 emission standard. The superstore was also required to report to the Council on the implementation of pollution measures and targets five and ten years after opening.

Planning conditions can also be used to set standards for the demolition and construction phase in new developments. These conditions may seek to stop excess dust escaping from sites and reduce emissions from the equipment used on (or accessing) the site. In London the Mayor has developed guidance on ‘the control of dust and emissions from construction and demolition’, implementation of which is commonly attached as a planning condition for new developments in the city. This guidance includes the use of DPFs on applicable construction equipment.

3.15 Planning conditions can also be used to set standards for the demolition and construction phase in new developments. These conditions may seek to stop excess dust escaping from sites and reduce emissions from the equipment used on (or accessing) the site. In London the Mayor has developed guidance on ‘the control of dust and emissions from construction and demolition’, implementation of which is commonly attached as a planning condition for new developments in the city. This guidance includes the use of DPFs on applicable construction equipment.

Corporate Social Responsibility

3.16 Corporate Social Responsibility (CSR) is a form of corporate self-regulation that a company builds into its business model. Essentially this is companies acting on their own initiative to improve their social and environmental impacts, rather than being required to do so by external regulation. Although CSR covers a far wider range of issues than simply pollutant emissions, many companies have included a strong focus on reducing emissions of greenhouse gases and/or air pollutants from their vehicle fleets. In some cases these voluntary initiatives have been recognised by local authorities or national charities, for example through voluntary accreditation or award schemes.

The Health Impacts of Particulate Matter Emissions

3.17 Particulate matter in the air is one of the biggest threats to public health that we face in urban areas. The latest medical evidence from the Government’s Committee on the Medical Effects of Air Pollution suggests that, annually, around 200,000 people in the UK have their lives shortened due to exposure to particulate matter. Particulate matter has a larger impact on public health in the UK than even many higher profile health issues, for example passive smoking.

3.18 Particulate matter is understood to be a ‘no safe threshold’ pollutant: the World Health Organisation states that there is no level below which there is no health impact. The European Union has established legally binding limits for the concentration of particulate matter in the air that the UK must meet. However, due to the ‘no safe threshold’ status there are still significant health benefits to be gained from reducing particulate matter concentrations even in areas that meet these European standards.
CASE STUDY
The South Yorkshire ‘Eco Stars’ Scheme

Whilst Low Emission Zones and licensing requirements are the main driver of retrofit, other fleet operators have taken on voluntary commitments to make their vehicles cleaner. This can help them meet Corporate Social Responsibility goals, and often put them in a better position to win business from the increasing number of businesses and public sector organisations that set tough environmental conditions for their suppliers.

The innovative ECO Stars is a fleet recognition scheme that provides a voluntary framework for fleet operators who want to display and improve the environmental performance of their fleets. The scheme rates the performance of fleets across six categories and awards a one to five star rating for overall performance. Advice and guidance on fleet improvement is also provided. The six categories are:

• Fleet composition
• Fuel management
• Driver skills development
• Vehicle specification / preventative maintenance
• Use of IT support systems
• Performance monitoring and management

The scheme has proved a great success, with several members proudly displaying their star rating on the side of their vehicles. The scheme was launched by South Yorkshire’s Care4Air partnership, but is now also in operation in other areas of the UK.

See www.care4air.org/ecostars/

3.19 Particulate matter is also associated with chronic ill health. The elderly, children and those with respiratory conditions such as asthma are particularly badly affected. Studies in the USA suggest that children growing up near busy roads suffer permanently reduced lung function that persists into their adult lives.

The Climate Impacts of Particulate Matter Emissions

3.20 The world is already warming due to the impact of greenhouse gases (such as carbon dioxide and methane) released by human activities. Action to reduce black carbon emissions could reduce this rate of warming: a 2011 report by the United Nations Environment Programme set out how measures to reduce black carbon (and other air pollutants with a warming impact such as ground level ozone) could radically reduce the amount of warming the globe will experience over the next 40 years. The Arctic would especially benefit from cuts in black carbon emissions, with the report calculating that the warming projected for the next 30 years would be cut by two thirds.

3.21 Measures to reduce black carbon emissions can complement those taken to reduce emissions of carbon dioxide (CO₂), the main gas involved in the process of global warming. CO₂ has a long life in the atmosphere and there is therefore a long ‘lag time’ before measures taken to reduce emissions have an appreciable impact on the concentration of CO₂ in the atmosphere. By contrast black carbon is removed from the atmosphere in a matter of days. Measures taken to reduce black carbon emissions quickly cut the amount in the atmosphere and reduce the warming it produces.
Section 4
Technical Options for Abating Particulate Matter Emissions

- Vehicles and equipment suitable for retrofit exhaust abatement
- Retrofit technologies
- Standards, certification and testing for retrofit systems
What Types of Vehicles and Equipment are Suitable for Retrofit?

4.1 All diesel vehicles and equipment are potentially suitable for retrofit exhaust abatement for particulate matter emissions. However, there are some limiting factors, including:

• Space – retrofit involves fitting additional equipment into the exhaust system. In most cases this will be through the addition of a stainless steel box containing the new equipment, although in some cases the equipment can be mounted in the original exhaust muffler. In most situations there is space available for the new equipment, however in some situations it may be difficult or impossible to fit new equipment.

• Cost – in some cases it may not be cost-effective to retrofit a vehicle or piece of equipment due to the cost of the abatement device relative to the value of the vehicle or machine.

4.2 Retrofit abatement is most commonly fitted on larger diesel vehicles and equipment, including HGVs, coaches, buses, railway locomotives and construction equipment. Retrofit of smaller vehicles such as cars is technically possible and commonly seen in areas where it is a requirement to have a filter fitted in order to gain entry to a low emission zone, for example in Germany. So far this has not been seen as an option in the UK, as there are currently no requirements for existing light duty vehicles (other than London taxis) to meet any particular emissions standards.

What Are The Main Technologies Available to Reduce Particulate Matter Emissions?

4.3 There are three main technologies used to reduce particulate matter emissions from diesel engines. The technology used will usually depend on the scale of emission reductions required, and the budget available for the retrofit. These technologies are shown in Table 4 below.

Table 4: Particulate matter abatement technology

<table>
<thead>
<tr>
<th>Technology</th>
<th>Particulate emission reduction potential</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mass</td>
</tr>
<tr>
<td>Wall-Flow Filter</td>
<td>&gt;95%</td>
</tr>
<tr>
<td>Partial Flow Filter</td>
<td>30-60%</td>
</tr>
<tr>
<td>Diesel Oxidation Catalyst</td>
<td>&lt;25%</td>
</tr>
</tbody>
</table>

4.4 The performance of retrofit technology can be expressed as the reduction in the total mass (weight) of the particle emissions achieved, or alternatively the reduction in the number of particles emitted. Current emission standards for particulate matter are set using particle mass. However, as medical evidence suggests that the smallest (and therefore lightest) particles are the most damaging to our health, future emission standards are likely to specify limits using particle numbers.
4.5 The three retrofit exhaust abatement technologies above can also reduce emissions of other pollutants, either by themselves or by use in combination with additional retrofit technology. For example, an oxidation catalyst also reduces emissions of hydrocarbons and carbon monoxide, and can be used in conjunction with a wall-flow filter to provide a system that reduces particulate matter, hydrocarbon and carbon monoxide emissions. Selective catalytic reduction (SCR) systems can reduce nitrogen oxide emissions when used on their own or in combination with an oxidation catalyst and filter.

What is a Wall-Flow Filter?

4.6 A wall-flow filter is one of the most common forms of DPF. Exhaust gases are forced into a series of channels made of a ceramic material that is porous to gases. The channels are blocked at alternate ends (i.e. half of the channels are blocked where the exhaust gases come in, and half at the other end of the filter) therefore to exit the filter the exhaust gases have to flow through the porous walls of the channels. Particles are unable to flow through the walls and are caught in the filter.

4.7 Wall-flow filters are the ‘gold standard’ for particulate matter abatement. They almost completely remove particles from the exhaust gases, including the very small ones. They are effective over a wide range of engine operating conditions (e.g. different rev ranges and engine loads).

4.8 Over time particulate matter builds up inside a wall-flow filter and it has to be cleaned using a process known as ‘regeneration’. A variety of strategies are used to regenerate the filter, but they tend to fall into two distinct categories. Passive regeneration take place continuously, for example by placing a catalyst before the filter or by coating a catalyst onto the filter itself. These catalysts can also reduce emissions of carbon monoxide and hydrocarbons by more than 90%. It is also possible to regenerate the filter by using engine heat in normal operation, but only at very high temperatures. Active regeneration strategies take place periodically when the vehicle or equipment’s Engine Control Unit determines that regeneration is necessary. Generally this is accomplished by raising the filter’s temperature by adjusting the engine conditions to increase the exhaust temperature.

4.9 Active filter regeneration can also be achieved via direct heating of the filter via electrical coils or a fuel burner. These systems are generally used when operating conditions mean that the engine is unable to raise the exhaust temperature for the time needed to regenerate the filter, for example in vehicles used exclusively in low speed urban driving situations or where space constraints mean the filter is installed some distance from the engine.
CASE STUDY
Construction Equipment in London and Switzerland

In 2006 the Greater London Authority and London Councils published Best Practice Guidance (BPG) on the control of emissions in construction and demolition. This is non-mandatory guidance that provides advice for air pollution mitigation measures to be included within a Code of Construction Practice. These mitigation measures fall broadly under the headings of effective site planning, construction traffic measures, demolition works and site activities.

The guidance includes advice on retrofitting construction and demolition equipment with suitable diesel particulate filters, backed by a register of approved filter models and suppliers. However, implementation of the guidance in London has been patchy, as local authorities have not yet enforced it widely. The Mayor has committed to the guidance, and is expected to consult on upgrading it to Supplementary Planning Guidance in the summer of 2012 to ensure that it can be more easily enforced.

Several other European countries and cities have also introduced policies to reduce emissions from construction equipment. In Switzerland, a country famed for its strict environmental policies, equipment with a power output over 37 kW has needed to be fitted with a particulate filter since 2009. This requirement has subsequently been extended to machinery with a lower power output (smaller equipment), demonstrating the wide range of machines that can be fitted with a filter as a cost-effective compliance option. The Austrian city of Vienna has also introduced a similar requirement.

What is a Partial Flow Filter?

4.10 A partial flow filter passes some of the exhaust gases from a diesel engine through a filter structure, typically a finely woven metal mesh or fleece. Particles are caught in the mesh as the exhaust gases pass through and exit the exhaust. The filter is continuously regenerated by burning the particles using heat from the engine and/or by oxidation with nitrogen oxide produced by an oxidation catalyst installed before the filter. Partial flow filters are commonly coated with precious metal catalysts that also allow them to reduce emissions of gaseous pollutants such as carbon monoxide.

4.11 Partial flow filters can be cheaper than wall-flow filters, however they are less effective at reducing particulate matter emissions. They are largely ineffective at reducing the smaller particles most strongly associated with damage to human health and warming of the climate.

What is a Diesel Oxidation Catalyst?

4.12 A diesel oxidation catalyst is formed of a honeycomb structure coated in precious metal catalysts. The hot exhaust gases are channelled through the device and, when the hot gases contact the catalyst metals, pollutants are oxidised to harmless gases. In terms of particulate matter emissions a diesel oxidation catalyst is only effective for the particles composed (or partially composed) of hydrocarbons: it does not remove black carbon particles from the exhaust. Consequently they reduce the mass of particles emitted but are largely ineffective at reducing the number of particles emitted, as most particles are composed at least partially of black carbon.

4.13 These types of catalyst are primarily used to reduce emissions of carbon monoxide and hydrocarbons in exhaust gases. Whilst they do reduce the mass of particulate matter emissions these reductions are unlikely to be enough to allow a diesel vehicle or piece of equipment to meet a modern emission standard. However, diesel oxidation catalysts are frequently used in combination with filters to reduce a wider range of pollutants from diesel exhausts.
What Standards and Certification Are Used for Retrofit Equipment?

4.14 A good knowledge of standards is essential for a successful retrofit. Vehicle and equipment operators will want to know:

- What emission standard the vehicle or equipment will meet after the retrofit
- Whether the vehicle or equipment will meet necessary standards after the retrofit; for example whether a vehicle will meet the requirements of the London Low Emission Zone or be eligible for a Reduced Pollution Certificate
- What checks are in place to ensure the retrofit equipment has been correctly fitted

4.15 Most retrofits for particulate matter will aim to improve on the emissions standard that the vehicle or equipment was originally constructed to meet. For example, the aim for a Euro II compliant HGV may be to raise its emissions performance to the Euro IV level, which would allow it to be used penalty free in the London Low Emission Zone.

4.16 In the UK Transport for London (TfL) has led the way in schemes to reduce particulate matter emissions from vehicles. The certification, testing and approval regimes TfL has set up to support the London Low Emission Zone can potentially be used by other areas of the UK when they introduce their own low emission schemes.

4.17 For vehicles TfL maintains an ‘approved devices’ list. This is a list of filter systems that have been tested and approved by TfL as suitable for meeting the current requirements of the London Low Emission Zone – Euro IV (for particulate matter) for larger vehicles, and Euro 3 for lighter vehicles. Note that the Euro IV particulate matter standard for heavy vehicles is the same as Euro V.

4.18 Similar lists also exist for construction equipment. For non road machinery the Energy Saving Trust maintains a ‘Non Road Mobile Machinery (NRMM) register of approved exhaust after treatment devices and suppliers’ – this is particulate matter abatement equipment that meets the requirements set in the Mayor’s Best Practice Guidelines on Dust and Emissions from Construction sites.

4.19 For other sectors and standards there are no current UK testing and certification regimes for particulate matter retrofit abatement equipment. However, equipment manufacturers are able to provide advice. Contact details for manufactures of approved devices are included in section 6. It is good practice to get quotes from at least three suppliers before proceeding with a retrofit.

What About Testing and Certification?

4.20 After retrofit equipment has been fitted it is important to have the installation checked to ensure it has been well fitted and is operating correctly – this will usually be done by your supplier. In addition to this if you wish to get a Reduced Pollution Certificate or Low Emission Certificate (to drive penalty free in the London Low Emission Zone) you will need to have your vehicle tested and certified.

4.21 Testing for both Reduced Pollution Certificates and Low Emission Certificates are carried out at Vehicle and Operator Services Agency (VOSA) test centres. For the location of your nearest centre call the VOSA Helpline on 0300 123 9000. Both tests can be carried out at the same time. Tests for Low Emission Certificates can also be carried out at your premises by an ‘authorised examiner’. Retrofit equipment suppliers will be able to provide advice on suitable local authorised examiners.
4.22 There are two parts to the test. The first is a physical inspection, where the examiner will inspect the engine, fuel system, exhaust system and the filter or other pollution control device fitted. If the test is for a Low Emission Certificate the examiner will confirm that the filter fitted has been approved by Transport for London. The second test is a smoke opacity test to check the actual emissions from the vehicle.

4.23 The emissions standard the vehicle is required to meet (via the smoke opacity test) will depend upon the type of vehicle and the abatement equipment fitted, i.e. it will test to see that the retrofitted equipment is doing what it is supposed to do.

4.24 Before taking your vehicle for a test you should make a number of checks. The first is to double check that the vehicle is likely to pass the test; the supplier of your retrofit equipment will be able to advise you if the equipment installed is likely to make the vehicle eligible. You should also ensure that:

- If needed, there is somebody present who can tilt the cab and reinstate it safely
- The engine type and chassis numbers are visible
- The fuel pump number is clean where appropriate
- The type number on the particulate filter is easy to inspect

4.25 There is no equivalent testing and certification regime for non-road equipment. For construction and demolition equipment fitted with filters in compliance with the Mayor’s Best Practice Guidelines the onus is on the site operator to ensure that approved filters have been fitted. Local authority staff may also make spot checks. It is still important for equipment operators to ensure that filters have been correctly fitted. Badly fitted filters may perform poorly (in terms of emission reduction) and can potentially damage engines and exhaust systems.
Section 5

Assessing Whether to Retrofit

- Financial costs and benefits of retrofit exhaust abatement
Section 5
Assessing Whether to Retrofit

Costs and Benefits for Vehicles

5.1 In order to determine whether it is cost effective to retrofit a vehicle the vehicle operator usually needs to determine three factors:

- The cost of retrofitting the vehicle, i.e. the cost of the filter, fitting, testing and annual maintenance
- The cost saving the retrofit will provide, i.e. reduced vehicle tax and / or Low Emission Zone fees
- The length of time the vehicle will provide these savings (i.e. the useful life of the vehicle, or the length of time before a Low Emission Zone introduces stricter standards that the vehicle cannot meet)

5.2 An operator may also wish to consider the wider benefits to society of reducing particulate matter emissions, in which case ‘monetised’ figures are available for the health damages caused by these emissions. The figures, available from the Government’s Department of Environment, Food and Rural Affairs, attempt to quantify the cost to individuals and society of ill health caused by particulate matter emissions. This approach may be of interest to operators with strong Corporate Social Responsibility policies or public service providers such as local government.

Costs and Benefits for Non-Road Machinery

5.3 The main driver for retrofit of non-road diesel machinery is binding agreements through planning conditions, contracts, etc. In the UK there are currently no financial benefits for retrofitting equipment outside of these agreements.

5.4 Construction equipment, railway locomotives, etc are usually leased rather than purchased by the operators. Equipment providers will usually charge more for retrofitted equipment or newer equipment that has been fitted with a filter from new. Operators will therefore need to make case by case decisions on whether this extra cost is worthwhile in order to take on a particular contract or job.

5.5 Similar considerations apply to licensed vehicles such as taxis where emissions standards must be met in order to gain a licence, for example in London where taxis must be constructed or retrofitted to meet standards set by TfL. Here vehicle operators must decide whether the costs of retrofitting are outweighed by the profits to be gained from operating under the licence.
CASE STUDY
Taxi Licensing in London

Black cabs are one of the iconic symbols of London. But in central London, where there are a large number of taxis, they are a very significant source of air pollution. In London the Mayor has started to address this by introducing pollution standards as part of the taxi licensing process.

Since 2008 taxi licences in London have only been issued to vehicles that meet the Euro 3 pollution standard (for all pollutants). Older taxis that do not meet the standard need to retrofit an approved filter and catalyst, be converted to Liquid Petroleum Gas or otherwise be re-engineered to meet the Euro 3 standard.

The Mayor is following up this action by introducing an age limit for taxis and emission standards for new vehicles entering the fleet. From 2012 a rolling 15 year age limit will be set for taxis so that no taxis over 15 years old will be licensed to operate in London unless they have a special exemption. From 2012 new taxis entering the fleet will be required to meet the Euro 5 emissions standard.

Costs of Diesel Particulate Filters

5.6 Table 5 opposite shows indicative costs for Diesel Particulate Filters. Note that these figures are indicative only and may vary substantially between vehicle classes and models. Generally DPF purchase prices increase with the size of the vehicle. Discounts may be available for volume buyers. In all cases retrofit equipment suppliers will be able to provide quotes.

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Unit Cost</th>
<th>Fitting Costs</th>
<th>Annual Maintenance Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small vans and busses</td>
<td>£1800 to £3500</td>
<td>£200 to £500</td>
<td>£100 to £200</td>
</tr>
<tr>
<td>Larger HGVs and buses</td>
<td>£3500 to £7000</td>
<td>£300 to £500</td>
<td>£150 to £350</td>
</tr>
</tbody>
</table>

Table 5: Indicative costs for diesel particulate filters

Source: Research for this guidance

Savings From Diesel Particulate Filters

5.7 Potential savings from retrofitting are:

• Cheaper vehicle excise duty through a Reduced Pollution Certificate (see table 3)

• Savings in Low Emission Zone fees (variable, but currently £100 to 200 per day for vehicles driven in the London Low Emission Zone)

5.8 Note that savings through a Reduced Pollution Certificate apply everywhere – it does not matter where the vehicle is driven. Low Emission Zone fees will only apply if a (non-compliant) vehicle is driven in a zone. The scale of savings is also very different: an operator will need to calculate whether Reduced Pollution Certificate savings offset the retrofit costs, whilst if a vehicle is regularly driven in a Low Emission Zone the size of the fees incurred will almost certainly make it economic to retrofit, or replace, the vehicle.
CASE STUDY
Low Emission Zones in Europe

Low Emission Zones are now common across Europe, and vehicles driven on the continent will need to be aware of any LEZs they may drive though. They are most numerous in Germany (60 LEZs implemented or planned), Italy (19 LEZs) and the Netherlands (15 LEZs). In these countries national Low Emission Zone frameworks have been established, backed by national databases of compliant vehicles.

Criteria vary between the various LEZs, as do the categories of vehicles covered. Some, for example Berlin, extend to private cars as well as larger vehicles. Most LEZs allow penalty free access to vehicles that have been retrofitted to the required standard, as well as vehicles that meet the standard from new. Vehicles need to be registered with the national or local authorities, and in some cases display a window sticker to show that they are compliant with the conditions of the LEZ.

The website www.lowemissionzones.eu provides more information to help organisations and individuals plan their journeys.
Useful Sources of Information on the Web

The websites below carry more information on diesel retrofit and the schemes designed to encourage it.

- www.dieselretrofit.eu – Website set up by AECC (Association for Emissions Control by Catalyst) to provide more information about the technology
- www.lowemissionzones.eu – A website detailing Low Emission Zones in the UK and Europe
- http://blackcarbon.org.uk – The Black Carbon Campaign website
- www.energysavingtrust.org.uk/england/content/view/full/3191 – The Energy Saving Trust’s register of approved devices for reducing emissions from construction equipment

Diesel Retrofit Abatement Equipment Suppliers

The table on the right shows suppliers of retrofit equipment certified under the London Low Emission Zone or the Non-Road Mobile Machinery register set up to support the London Mayor’s guidance on construction and demolition.
Black carbon – Soot arising from vehicle exhausts, and also domestic and industrial combustion. Black carbon can have a significant warming effect on the climate, as it reduces the amount of solar radiation reflected from the Earth’s surface.

Carbon dioxide (CO₂) – CO₂ is exhaled by living organisms, as well as emitted from the combustion of fuels. CO₂ in the atmosphere exists in a ‘carbon cycle’ where CO₂ emitted into the atmosphere is balanced by processes that remove it, keeping concentrations in the atmosphere roughly steady. Emissions from human activities have upset this balance, and concentrations in the atmosphere are climbing. As CO₂ is a greenhouse gas this is causing the Earth’s climate to change.

Committee on the Medical Effects of Air Pollution (COMEAP) – The Government’s advisory body on the human health impacts of air pollution.

Diesel Particulate Filter (DPF) – A device in the exhaust system of a diesel vehicle or piece of equipment that filters particulate matter emissions from the exhaust gases, preventing it from being emitted into the air.


Greenhouse Gas – Any atmospheric gas that traps heat in the atmosphere. Like the panes of glass in a greenhouse, greenhouse gases allow radiation from the sun to pass through, but trap heat re-radiated from the Earth’s surface.

Local Air Quality Management (LAQM) – LAQM is the system under which local authorities review and assess air quality in their areas against agreed national standards. Where air quality is found to be in breach of the standards they must declare an Air Quality Management Area and produce an action plan to pursue attainment of the standards.

Low Emission Strategies – Packages of measures applied to reduce emissions of both air pollutants and greenhouse gases from new (or significantly altered) developments. They are secured by local authorities via the planning system, using a combination of planning conditions and obligations.

Nitrogen Dioxide (NO₂) – A common air pollutant emitted by combustion processes, including road vehicles, aircraft and domestic and industrial combustion. NO₂ is a respiratory irritant, and in strong sunlight is a precursor for ozone formation.

Non Road Mobile Machinery – A catch all term for mobile diesel powered machinery whose primary purpose is not to be driven on a road. Examples include construction equipment, railway locomotives and agricultural machinery.

PM₁₀ and PM₂.₅ – Airborne particle pollution, with the number denoting the appropriate size of the particle in micro-meters. Fine particles are taken deep into the lung’s membrane, and can even cross over into the bloodstream. Particle pollution is strongly associated with illness and premature death from heart and lung disease. Common sources of particles include diesel vehicles, solid fuel combustion and vehicle tyre and brake wear.
Reduced Pollution Certificate (RPC) – Heavy vehicles that have been retrofitted to a higher emission standard (for example by fitting a diesel particulate filter) can apply for a Reduced Pollution Certificate. If they pass a test and receive the certificate they pay lower Vehicle Excise Duty (road tax) than an equivalent vehicle without the certificate.

Transport for London – A public body that regulates and funds transport in London. It is under the control of the Mayor of London.

Ultra Low Sulphur Diesel (ULSD) – Diesel fuel with a sulphur content of less than 10 parts per million. All road diesel sold in the UK is now ULSD.
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