London Low Emission Construction Partnership

Efficacy of abatement and mitigation techniques used in the control of dust and emissions in the demolition and construction industries

An evidence based literature review

September 2014

Daniel Marsh and David Green

Environmental Research Group

King's College London

Title	Efficacy of abatement and mitigation techniques used in the control of dust and emissions in the demolition and construction industries

Customer	London Low Emission Construction Partnership

Customer Ref	-

File Reference	

Report Number	

Environmental Research Group
King's College London
4th Floor
Franklin-Wilkins Building
150 Stamford St
London SE1 9NH
Tel 020 7848 4044
Fax 020 7848 4045

	Name	**Signature**	**Date**
Authors	Daniel Marsh		
Reviewed by	David Green		
Approved by	Gary Fuller		

Table of Contents

Introduction

This document is the result of an extensive literature review to the latest research available for the control of dust and emission and to establish what is currently available and to identify areas where there could be substantial benefits from further research.

This document will help the London Low Emission Construction Partnership (LLECP) to focus its resources on targeting the abatement and mitigation techniques that are likely to deliver the greatest benefits both in dust suppression, emission reduction and in cost.

This document is a work in progress and will be updated as new research becomes available.

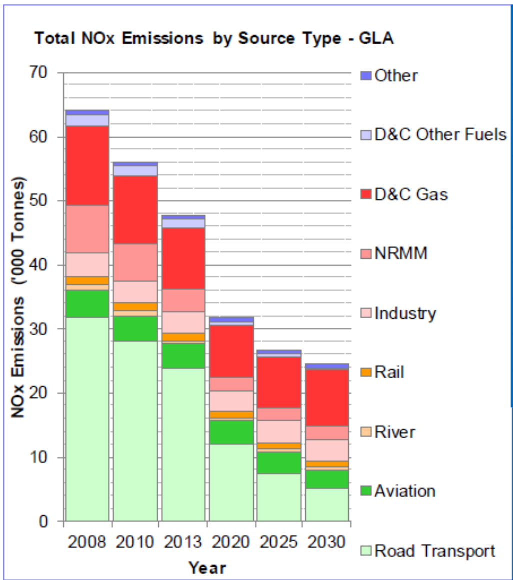
Atmospheric Emissions Inventories

The UK National Atmospheric Emission Inventory (NAEI) is made up of the Greenhouse Gas Inventory (GHGI) and the Air Quality Pollutant Inventory (AQPI). To deliver these estimates, the GHG inventory team collect and analyse information from a wide range of sources – from national energy statistics through to data collected from individual industrial plants. This information is then used for apportionment of UK emissions to known sources and allows us to track trends and measure the impact of any interventions across various sectors.

The London Atmospheric Emissions Inventory (LAEI) is based on a proportion of the NAEI emissions. The construction contributions are determined by employment in the construction sector and distributed geographically using the London Development database (LDD). The latest LAEI estimates that 7% of the NO_x, 8% of the PM_{10} particles and 14.5% of the $PM_{2.5}$ particles emitted in London come from machinery used in the construction sector with only 1% of the PM_{10} particles being fugitive or nuisance dust. A further 22% of the PM_{10} in London is particles from all sources that are resuspended either by wind or the movement of vehicles passing over them.

The information in the latest LAEI will be used to determine where research conducted through the LLECP would bring the greatest emission reduction benefits.

The latest LAEI was published in 2016 and contains emission estimates for 2013 and can be downloaded at: https://data.london.gov.uk/dataset/london-atmospheric-emissions-inventory-2013



Emissions (Tonnes) by	2008	2010	2013	2020	2025	2030
Road Transport	31,774	28,049	23,853	11,995	7,535	5,018
Aviation	4,210	3,864	3,759	3,557	3,212	2,867
River	825	775	500	573	623	659
Rail	1,281	1,236	1,205	861	861	861
Industry	3,604	3,604	3,353	3,353	3,353	3,353
NRMM	7,625	5,638	3,571	2,117	2,057	2,057
D&C Gas	12,178	10,712	9,397	8,171	7,994	8,690
D&C Other Fuels	1,863	1,553	1,363	550	394	343
Other	599	580	661	676	679	704
Total	63,957	56,011	47,661	31,852	26,708	24,553

Notes:

The emissions are combined into reasonably self explanatory "Source Types".

However, the categories: "Industry", "NRMM" and "Other" require further explanation:

- **Industry:** is the total emission from Part A and Part B industrial processes, combined.
- **Non-Road Mobile Machinery (NRMM):** is the total emissions from construction and industrial off road machines, combined.
- **Other:** is the total emission from a number of small sources including: agriculture, outdoor fires, garden emissions, forests, waste and waste transfer sites, combined.

Road Surface Dust

Although particulate matter emissions are well known to have negative health impacts including respiratory, cardiovascular and carcinogenic diseases the information about the effectiveness of mitigation measures to remove deposits from the road surface and prevent resuspension is still quite limited in scientific papers for the public highway and even more so relating to dust trackout from the demolition and construction industry.

Surface cleaning

Studies into the effectiveness of street cleaning activities found that water flushing and mechanical sweeping combined with water flushing achieved reductions of >90% in deposited dust loads on the road. The results also indicate that street washing is an effective mitigation technique of reducing ambient kerbside concentrations PM_{10} concentrations with a measured reduction of 7-10% (Amato, Querol et al. 2009)

Karanasiou et al.(2011) quantified the contribution of road dust to PM_{10} and evaluated the effects of street washing on the mitigation of resuspension. PM_{10} daily concentrations during dry and unwashed conditions were found to be 2-15% higher than those present during the day after the nightly street washing. However the diurnal variation of PM_{10} revealed that the reduction was short lived and only observed during the morning hours after night washing. It was found to have little or no impact in the reduction of $PM_{2.5}$ concentrations; this was likely due to the more dominant $PM_{2.5}$ sources in the road environment such as vehicle exhaust emissions (Karanasiou, Moreno et al. 2012). It was concluded that street washing would be more effective in the reduction of coarse particles if carried out just before peak traffic hours.

Some insight into the efficacy of different cleaning methodologies has been gained from studies relating to the efficiency of sediment removal, however they yield variable results and often relate to the particle size and the method of removal. For instance, mechanical broom sweepers are more effective at picking up larger particles (>1000-125 um) whilst regenerative air sweepers are recommended for finer particles (< 100um). A number of factors influence the effectiveness of these street sweepers for the removal of dust sediments; these include environmental factors (climate, season) type of vehicle (sweeping mechanism), particle size and loadings, sweeping frequency and timing, surface type and moisture.

A combined approach, using water flushing and then with sweeping has been shown to be effective for only short periods for Total Suspended Particles (TSP) (3-4 h) and even less for PM_{10} (2-3 h) although the authors felt that this may be due to the wetted surface conditions leading to a reduction in resuspension of PM_{10} and not the actual cleaning of the road (Chang, Chou et al. 2005). Despite the uncertainty in results due to different equipment used and the environment in which they have been assessed it is clear that a combination of sweeping followed by washing is a reliable practice to mitigate PM emission from resuspension on a paved road (Amato, Querol et al. 2010). Therefore, where there is a higher loading, such as in the proximity of demolition and construction activities it may be best to use a tandem operation, where the streets are first cleaned with a mechanical street cleaner to remove the larger particles, followed by a regenerative-air street cleaner to remove finer particles.

One area where there seems to be no research is the effectiveness of street cleaning activities and the condition of the street surface. In areas where there is a high volume of heavy vehicles passing over the public highway there is often visible signs of wear, fracturing and damage to the road surface which would almost certainly reduce the ability of mechanical street cleaners to clean efficiently. Consideration should therefore also be given to the condition of the road surface outside the site boundary when assessing the potential impacts of street cleaning and re-surfacing may be required to allow the cleaning process to be effective.

Many on-site roads and haulage routes across demolition and construction sites are temporary and therefore have an unmade road surface. Studies on the effect of vehicle characteristics on unpaved roads have found that the magnitude of emissions was controlled primarily by vehicle speed and vehicle weight, both of which had a linear effect on the emissions, this suggest that the emissions are linearly dependant on a vehicle's momentum. Other physical characteristics of the vehicles (e.g. the number of wheels, undercarriage, area, height) did not appear to heavily influence the emissions (Gillies, Etyemezian et al. 2005). Controlling vehicle speed on unmade roads may therefore be a simple method of reducing emissions.

Use of Dust Suppressants

When a dust suppressant such as Calcium Magnesium Acetate (CMA) is sprayed onto a surface it forms a hydroscopic coating, keeping the surface 'damp'. When particulate matter comes into contact with a treated surface it is less likely to become resuspended, thus reducing the amount of PM in the air. The CMA will only affect particulate matter that comes into contact with the treated surface, therefore the greater the area treated the larger the potential benefits that will be.

Studies in Scandinavia found that application of CMA-solution applied to the road surface of a highway reduced the daily PM_{10} levels by 35% on average. The use of CMA can therefore be an effective measure to reduce peaks of PM_{10} during very dry road conditions. The same study also found that intense washing of the verge with high pressure water systems only resulted in a marginal reduction on PM_{10} levels (~6%). Intense sweeping of roads in the city centre was also found to have none or marginal effect on PM_{10} concentrations (Norman and Johansson 2006).

Earlier trials of Calcium Magnesium Acetate (CMA) dust suppressant on paved roads in London found that there was an observable level of improvement in 24 hour PM_{10} concentrations during low intensity application periods, with a potential reduction of about 10% at kerbside locations. Analysis of results from a more intense period of treatment suggest that there was a greater level of improvement, with approximately 14% reduction achieved. Calculations for the smaller size fractions of $PM_{2.5}$ and PM_1 suggest that improvements of around 3% were achieved during the intense treatment period. CMA interventions are anticipated to primarily affect larger sized particles so the lower improvements achieved would be expected for the smaller size fractions (Deakin 2011).

Subsequent trials carried out to evaluate the impacts of using CMA as a dust suppressant in London during 2011 indicated that there was limited impact when applied to the public highway. However, there was a far greater impact recorded in test areas close to industrial sites characterised by waste transfer stations and other processes generating unusually high levels of airborne dust. Benefits of CMA application were identified where the dust suppressant was applied to road adjacent to the sites and at the process yards themselves. One of the study areas, Horn Lane in Ealing, is adjacent to a mixed use industrial area comprising of a waste transfer station, aggregates handling, a cement batching plant and several other smaller operations. This site indicated a clear drop in local PM10 concentrations in the hour following on-site CMA application of between 31% and 59% relative to the control.

For construction sites it was therefore recommended that CMA should be considered on haulage routes on and off site during the demolition and construction phases of large developments (Ben Barratt 2012). Consequently, the GLA have recommended the dust suppressant for use at road sides and along roads close to and within construction and industrial waste sites with high levels of local PM_{10} pollution (GLA 2014). In these cases, where CMA is applied to unpaved roads and haulage routes on construction sites there must be consideration made to dust being carried from the unpaved areas to the paved roads due to the strong dust binding effects of the CMA. To avoid trackout occurring onto the public highway constructions sites where CMA in being used should ideally also be equipped with wheel washing facilities (Project 2012).

References

Amato, F., et al. (2009). "Evaluating urban PM10 pollution benefit induced by street cleaning activities." Atmospheric Environment **43**(29): 4472-4480.

Amato, F., et al. (2010). "A review on the effectiveness of street sweeping, washing and dust suppressants as urban PM control methods." Science of The Total Environment **408**(16): 3070-3084.

Ben Barratt, D. C., Gary Fuller, David Green and Anja Tremper (2012). Evaluation of the impact of dust suppressant application on ambient PM10 concentrations in London.

Chang, Y.-M., et al. (2005). "Effectiveness of street sweeping and washing for controlling ambient TSP." Atmospheric Environment **39**(10): 1891-1902.

Deakin, D. U. (2011). Targeted Application of Calcium Magnesium Acetate (CMA) Pilot Study Monitoring Report.

Gillies, J. A., et al. (2005). "Effect of vehicle characteristics on unpaved road dust emissions." Atmospheric Environment **39**(13): 2341-2347.

GLA (2014). The Control of Dust and Emissions during Construction and Demolition, Greater London Authority.

Karanasiou, A., et al. (2011). "Road dust contribution to PM levels – Evaluation of the effectiveness of street washing activities by means of Positive Matrix Factorization." Atmospheric Environment **45**(13): 2193-2201.

Karanasiou, A., et al. (2012). "Variation of PM2.5 concentrations in relation to street washing activities." Atmospheric Environment **54**(0): 465-469.

Norman, M. and C. Johansson (2006). "Studies of some measures to reduce road dust emissions from paved roads in Scandinavia." Atmospheric Environment **40**(32): 6154-6164.

Project, C. E. L. (2012). CMA+ Instuction Manual 1.1 for the reduction of fine-dust (PM) pollution through the application of a liquid 'fine-dust glue' (Calcium Magnesium Acetate)

Non-Road Mobile Machinery

The London Atmospheric Emissions Inventory (LAEI) has identified that the construction industry contributes 12.9% of PM_{10}, 17.3% of $PM_{2.5}$ and 11.6% of NOx of the total emissions in London each year. From further work looking at the construction sources in more detail carried out at King's College London it appears that these emissions are dominated by non-road mobile machinery (NRMM).

NRMM is defined as any mobile machine, item of transportable industrial equipment, or vehicle - with or without bodywork - that is:

- not intended for carrying passengers or goods on the road
- installed with a combustion engine - either an internal spark ignition (SI) petrol engine, or a compression ignition diesel engine

Examples of non-road mobile machinery include, but are not limited to:

- garden equipment, such as hedge trimmers and hand-held chainsaws
- generators
- bulldozers
- pumps
- construction machinery
- industrial trucks
- fork lifts
- mobile cranes

In the UK, the legislation governing emissions produced by engines fitted in NRMM is the Non-Road Mobile Machinery (Emission of Gaseous and Particulate Pollutants) Regulations 1999, as amended. This sets emission standards for carbon monoxide, hydrocarbons, oxides of nitrogen and - for diesel engines - particulate matter.

Engines installed in NRMM are split into categories for spark ignition (SI) and compression ignition (CI), and then further classified according to the engine power rating. These categories are then given limits for specified gaseous output, more commonly known as the engine's 'stage'.

SI engines of up to 19kW net power that are used in land-based portable or mobile machinery are covered by the NRMM regulations.

Variable-speed and fixed-speed CI engines are covered where their rated power is between 18kW and 560kW (equivalent to 24hp to 760hp) ((DfT) 2014).

In theoretically perfect combustion, carbon dioxide, water and nitrogen are the end products. In reality the incomplete combustion of diesel fuels results in emissions that include oxides of nitrogen (NOx), carbon monoxide (CO), carbon dioxide (CO_2), water (H_2O) and unburned hydrocarbons (HC). There are also un-burnt carbon particles, as well as engine oils, debris, soot and ash particulates, known as particulate matter (PM) (GenCat 2013).

Reducing emissions from construction equipment through emission standards

The Greater London Authority (GLA) have recently announced new standards which would make London the first city in the world to require standards for construction equipment for emissions of NOx and PM and are intended to lead to a 40% reduction by 2040 helping London to meet the EU compliance targets for nitrogen dioxide (NO_2) (GLA 2014).

Construction machinery generally is in service for longer than on-road vehicles and combined with the fact that the emission standards for the engines used in machinery lag behind their on-road counterparts mean that machinery pollutes more and for longer (Hartley 2014).

New standards have been set by the GLA to create a low emission zone (LEZ) for NRMM in the Supplementary Planning Guidance: The Control of Dust and Emissions during Construction and Demolition (GLA 2014)to be implemented from 1st September 2015.

NRMM of net power between 37kW and 560kW used in London will be required to meet the standards set in Stage IIIA of EU Directive 97/68/EC and its subsequent amendments (Dieter Vandenbroucke 2010). Developments in Central London and Canary Wharf will be required to meet the more stringent Stage IIIB emission standard. Effectively all NRMM over ten years old will need to be replaced or retrofitted with emission reduction technology.

There is recognition of the costs of implementing this policy and as such the 2015 standards for NRMM LEZ will only apply to major developments in outer London, removing small operators from the scope of the proposals until 2020.

An inventory of all NRMM should be kept on site stating the emission limits for all equipment. All machines should be regularly serviced and logs should also be kept on site for inspection.

In order to discourage a mass engine refits of NRMM to petrol engines to get around the new diesel emission standards the European Commission have applied the same stringent standards (Kent 2014).

A cost benefit analysis was carried out on behalf of the GLA in 2013 which considered different modelled scenarios for regulating NRMM in London in order to reduce emissions within the Ultra Low Emission Zone (ULEZ). The outcome of this study was that it was not cost effective to place an age limit on equipment used as this would incur an ongoing cost as each year as the oldest equipment is replaced and the emissions savings are likely to be significantly smaller than those achieved through the introduction of a specific emission standard for London.

This study based on the NAEI NRMM model did consider that the values obtained were indicative only as construction methods have developed and newer equipment may be omitted with older equipment included no longer used. It was recommended that a new specific inventory would need to be developed in order to estimated more accurate emissions and costs and to gain a greater understanding of what equipment is used and where (Ricardo-AEA 2013).

Consideration should also be given to the draft EU NRMM directive limits as although it introduces some control and limits NOx emissions to 0.67 grams per KiloWatt hour (kWh) it also exempts the largest and most polluting diesel engines with a power rating of more than 560 KWh (EurActiv.com 2014).

Despite not being covered by the directive these larger engines are still accountable for quite a large amount of the total NRMM emissions, 9% of NOx and 12% of PM (Commission 2013).

Information about life expectancy for NRMM used in the UK construction industry is much unknown, often it can be quite short for intensively used equipment, possibly as little as two years, and equipment may also have ‘several lives, being re-engined and sold on to new owners. Further consideration should also be given to equipment owned by plant hire companies and to what proportion of the time typically the machine is actually on hire (Netcen 2004). This is an area where further research would be beneficial.

Additional methods of reducing emissions from construction equipment

The EPA produce advice for construction fleet operators to further reduce the emissions beyond that achieved through emission standards alone ((EPA) 2006), ((EPA) 2007), ((EPA) 2004). This includes reducing engine idling, use of cleaner fuels and installation of pollution control equipment.

Engine Idling

Idling engines waste fuel, with a large diesel engine wasting up to one gallon of fuel for each hour it is left idling reduce engine life as well as contributing to emissions.

Unnecessary idling can occur when vehicles wait for extended periods during loading and unloading of materials or supplies or when equipment is not being used.

An idling engine does not generate enough heat to achieve proper combustion. Deposits can build up on the piston and cylinder walls, contaminating the oil and creating friction that increases the wear on engine components. Limiting idling will also lead to a reduced maintenance as reduced wear will require less frequent oil changes and engine rebuilds and therefore lower operating costs.

Often modern NRMM has idling management systems build in that allows for either mechanical or electrical shutdown of engines after they have been idling for a preset time period. Operators should check with the manufacturer for specific equipment information and that these idling reduction control features have been enabled.

Fleet managers can plan ahead to efficiently manage the work flow within a project to prevent idling vehicles whilst waiting for deliveries and maximise equipment use across the site. A low cost solution to idling can simply be through behaviour change and raising awareness amongst operators that most modern equipment does not require warm-up or cool-down periods and of the cost implications to the company of idling will encourage equipment operators to assist by switching off their engines when not in use.

Measuring performance and tracking fuel consumption can be a good indicator of the success of idle reduction policies; although this may have administrative costs there is software available to collect this information. Posting these results can allow operators to see how they compare to others and help encourage a ‘switch it off’ culture.

The engine on some NRMM also runs additional cab services such as heating and air conditioning as well as powering other functions such as lifting etc. It is possible to use an auxiliary power unit (APU)

Use of Cleaner Fuels

A reduction in pollution can be achieved through the use of cleaner fuels Alternatives include low sulphur diesel (LSD), ultra low sulphur diesel (ULSD), biodiesel, blends of biodiesel with petroleum diesel and emulsified diesel.

Low sulphur diesel has sulphur content of 300 – 500ppm and reduces particulate matter (PM) by 10 – 20% compared to non-road diesel fuel (which has a sulphur content or 3000 – 5000ppm).

Ultra low sulphur diesel is a refined, cleaner fuel with a sulphur content of 15ppm or less that can be used in any diesel engine. It reduces the fine PM emissions between 5 – 9%, depending onb baseline sulphur content, but when combined with a diesel particulate filter (DPF) it can lead to emission reductions of 60 – 90%.

Biodiesel is produced from new and used vegetable oils and animal fats. Biodiesel is safe, biodegradable and leads to a reduction in particulate matter (PM) , carbon monoxide (CO) and hydrocarbons (HC) but it can lead to an increase in the nitrogen oxide (NOx) emissions from the engine. It can be used in its pure form (B100) if engine modifications are made but is more usually blended as 20% biodiesel with 80% regular diesel (B20) which leads to a 10% PM reduction but increases NOx emissions by 2%. Biodiesel can also reduce lifecycle CO2 emissions since its production employs a closed carbon cycle that grows and processes plants to produce new fuel ((EPA) 2002).

Biodiesel may also have a cleaning effect on the engine, resulting in an engine that produces less smoke, runs more smoothly and produces less noise.

Emulsified diesel is a blended mixture of diesel, water and other additives and leads to a reduction in both PM and NOx emissions. Emulsified diesel can be used in any diesel engine but the addition of water reduces the energy content of the fuel which in turn reduces engine power and fuel economy. Emulsified diesel can reduce NOx emissions between 10 – 20% and ultra fine PM between 50 – 60%.

Studies have indicated that compared to ULSD both bio-diesel (BD) and butanol diesel (DBu) blends can effectively reduce the particulate mass and elemental carbon emissions with butanol being more effective than bio-diesel (Zhang and Balasubramanian 2014).

Compared with biodiesel fuels, butanol blended fuels have a lower gas exhaust temperature and emit lower PM and NOx levels although they also exhibited a higher level of CO and unburned HC emissions (Yilmaz, Vigil et al. 2014)

In petroleum-diesel and biodiesel blended fuels the emissions of PM and particulate OC decrease significantly as the percentage of waste-edible-oil-biodiesel is increased. Addition of acetone and isopropyl alcohol to produce biodieselhols leads to further the concentration reductions of PM and particulate OC emissions (Koc and Abdullah 2013, Tsai, Chen et al. 2014, Tsai, Chen et al. 2014, Yilmaz, Vigil et al. 2014)

As biodiesel and biodiesel fuel blends become more widely used in the construction and demolition industry their PM and NOx emissions will become more important and further studies should be carried out.

Pollution control equipment

Retro fitting of older equipment with pollution control equipment such as a diesel oxidation catalyst or diesel particulate filter directly onto the engines exhaust system will reduce emissions from construction equipment.

Diesel oxidation catalysts (DOC's) are similar to a catalytic convertor as used in on road vehicles and can lead to a reduction on PM emissions of between 20 – 40%, HC by 50% and CO by 40%. Catalytic convertors use catalytic chemical conversion to transform CO and unburned HS's into non-toxic carbon dioxide and water. This conversion is carried out through a metallic honeycomb substrate coated with platinum, palladium and rhodium (GenCat 2008).

Flow-Through Filters (FTF's) or through-wall filters can be used a wide variety of construction equipment and provide greater emission benefits than a DOC. A FF can reduce VOC and CO emissions by 50 to 89% and PM emissions by approximately 50% ((MassDEP 2008). A FTF includes a flow-through catalyst core and is very similar to a DOC, but it uses a different type of core material to hold the catalyst. Different manufacturers use wire mesh, wire fleece, or sintered metal cores, all coated with a precious metal catalyst and packaged into a metal container. As in the DOC the catalyst promotes the oxidation of unburned PM, VOCs and CO in the exhaust stream passing through the device. Due to the core configuration individual PM particles have greater opportunity for contact with the catalyst site than in a standard DOC. FTF's require a minimum exhaust gas temperature and this limits their use compared with DOC's and DPF's.

Diesel particulate filters (DPF's) are ceramic devices that collect PM in the exhaust stream by means of physical filtration; the high temperature of the exhaust heats the ceramic structure and causes the particulates to oxidise into less harmful components, once captured the accumulated deposits must be dealt with is a safe and secure manner. When DPF's are used with ULSD reductions in particulate matter of up to 90% can be achieved, with a reduction in both HC and CO emissions of 60-90%.

Retrofit technologies must fit the equipment application. Some technologies have exhaust temperature requirements in order to allow them to achieve the greatest emission reductions.

Passive diesel particulate filters need to operate above a certain temperature in order to ensure regeneration, prevent the filter from becoming blocked and potentially cause engine damage due to increased backpressure. This should be a consideration when fitting to equipment that has long periods of low-load operating or idling as the required temperatures will not be achieved.

There are two types of DPF – non-regenerative where the filter is removed and replaced with a fresh one at the end of its working life and regenerative where the filter is reused.

Non-regenerative filters are generally constructed from fibre matting in which materials such as steel wool and fibre glass are used. Housed in a steel canister the particulate matter is trapped within the fibre matting. When full the filter must be replaced with a clean one. These types of filter have a life of around 300 working hours and are therefore best suited for low usage applications or on equipment that is only used for short periods.

Regenerative filters are commonly produced from ceramic materials such as cordierite or silicon carbide. Constructed as a honeycomb monolith, channels are blocked at alternate ends forcing the exhaust stream to flow through the walls between the channels, known as 'wall flow'. The PM cannot pass through the walls so is deposited within the channels and these deposits are then burnt away. Due to the high temperatures involved in regeneration these filters are best suited to high-use applications where the exhaust gas temperature (EGT) is high.

Diesel particulate filters can be fitted to almost any piece of machinery or vehicle, for on-road or off-road use, that uses a diesel engine.

Engine replacement or 're-powering' is the replacement of an older diesel engine with a new, low emission engine system. 'Upgrading' means the addition of emission reduction components, often during an engine rebuild. Emission upgrade kits can often be fitted at the time of a rebuild which is a fairly low cost option to improve the emission performance, improve fuel economy, reduce maintenance costs and extend an engines life.

Emission reduction benefits will depend on the originally certified emission level of the vehicle and the replacement engine used. Average emissions reductions vary from 25 up to 75%

Electrification

Electrification involves employing electric or hybrid equipment on site. Currently there is limited information about heavy duty electric or hybrid vehicles as these technologies are still under development.

Hybrid diesel-electric equipment

As Tier 4 Final engines are phased in throughout the US in 2014 the electric-diesel revolution is just getting started. The diesel-electric hybrid equipment allows you to run with a slightly smaller engine at a lower RPM, this directly translates into fuel savings, lower NOx and PM emissions and longer engine life (DieselForum.org 2013).

Electric drive systems have an infinitely variable power band. Some proponents of the diesel-electric earthmoving equipment are also promising that, with all the surplus electric power being generated, they may be able to do away with alternators and electrify components that normally hang off the serpentine belt such as lube, air conditioning and water pumps, therefore greatly reducing parasitic loads. It has even been suggested that it might be possible to drive hydraulic implements with hybrid electricity instead of flywheel powered hydraulic fluid one day (Jackson 2014)

Further advantages of using diesel –electric hybrids is the time saved on site having to track the vehicle back to fuel tanks to recharge as well as significant engine noise reductions.

This technology is still in its early days and the fuels savings, which will be a driver behind sales, and emission reductions in real-world operation are still being evaluated. A fuel saving of up to 28% and reduction in emissions of up to 90% compared with conventional equipment has been reported. Some tests found these to be significantly less when tested in comparison with the latest non-hybrid equipment with new engine technology and tail-pipe scrubbers and these are not representative of many of the older diesel equipment commonly in use today.

Both hybrid diesel construction equipment and new conventional construction equipment are much cleaner than old diesel equipment. The drawback is that the hybrids cost 20 per cent more than conventional new equipment (Grayson 2013, Johnson 2013, Nealon 2013).

Hybrid power generators for construction are also available. Inefficient generator use is common across UK construction sites in the UK. Traditionally the same generator that supplies high daytime loads is also left running to supply lower overnight loads. Generators run less efficiently at very low loads, as engines are unable to produce the same number of kWh of energy per litre of fuel when delivering power outputs of less than 25% of their generating capacity. This burns litres of fuel unnecessarily. Generators consume a baseline of fuel, even if they are delivering no power. Running at very low loads can cause damage and reduce the life of the generator.

Hybrid power generators (HPG) have an on-board intelligent management system which automatically manages the supply of power during lower loads; they have onboard battery capacity and can switch off the main diesel generator when higher loads are not required. Use of HPG's can reduce fuel consumption by up to 50%, reduce diesel carbon emissions by up to 50% and also reduce maintenance costs due to the reduced running time. Additionally HPG's are capable of using a range of renewable technologies such as solar, wind, battery and biodiesel (FireFly 2014).

Electrification of long-term construction sites

Using power direct from the national grid rather than on-site diesel generators can be a low cost solution that will reduce on-site emissions and reduce noise levels as well as reducing emissions from both plant and fuel delivery vehicles. This may then lead to further opportunities for site operators to use electric equipment rather than diesel. There may be cost saving implications with electric equipment having less components requiring maintenance.

A significant barrier to the electrification of long-term construction sites is the amount of time it takes for UK Power to install a suitable sub station from the time that work commences. Better communication between the developer and the power supply companies would lead to less dependency on traditional

References

(DfT), D. f. T. (2014). "Outline of Non-Road Mobile Machinery (NRMM) Emissions Regulations." from http://www.dft.gov.uk/vca/enforcement/non-road-mobile-mach.asp.

(EPA), U. E. P. A. (2002). A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions.

(EPA), U. E. P. A. (2004). Summary and Analysis of Comments: Control of Emissions from Nonroad Diesel Engines.

(EPA), U. S. E. P. A. (2006). "Reducing Emissions from Construction Equipment." from http://www.epa.gov/region1/eco/gb3/pdfs/GB3_ConstructionEmissions.pdf.

(EPA), U. S. E. P. A. (2007). Cleaner Diesels: Low Cost Ways to Reduce Emissions from Construction Equipment.

Commission, E. (2013). Stakeholder Consultation on the revision of the Directive 97/68/EC on emissions from nonroad mobile machinery engines.

DieselForum.org (2013). CLEAN DIESEL TECHNOLOGY FOR OFF-ROAD ENGINES AND EQUIPMENT: TIER 4 AND MORE.

Dieter Vandenbroucke, A. V. H., Laurent Francx (2010). Study in View of the Revision of Directive 97/68/EC on Non-Road Mobile Machinery (NRMM) (An Emission Inventory and Impact Assessment), Arcadis.

EurActiv.com (2014) Draft EU road machinery laws omits PM limit and emissions count.

FireFly (2014) HYBRID POWER GENERATORS FOR CONSTRUCTION, INFRASTRUCTURE AND PLANT HIRE.

GenCat (2008) Case Study CO, HC & PM Emission Reduction - Perkins 4016TAG2.

GenCat (2013) How to reduce black smoke and carbon emissions from diesel engines - GenCat Diesel Particulate Filters.

GLA (2014). The Control of Dust and Emissions during Construction and Demolition, Greater London Authority.

GLA (2014). "Mayor's new scheme to tackle old, polluting construction machinery & boost air quality." from http://www.london.gov.uk/media/mayor-press-releases/2014/08/mayor-s-new-scheme-to-tackle-old-polluting-construction.

Grayson, W. (2013) Study: Hybrid construction equipment emits more harmful pollutants than diesel-only machines

Hartley, G. (2014). Constructing a cleaner future. G. Hartley, Energy Savings Trust.

Jackson, T. (2014) How 3 diesel-electric and hybrid construction machines are waging war on wasted energy

Johnson, D. K. C. (2013). Hybrid Off-Road Equipment In-Use Emissions Evaluation.

Kent, M. (2014). "Emission legislation on the horizon." Retrieved 17/9/2014, 2014, from http://www.adjacentgovernment.co.uk/housing-building-construction-planning-news/emission-legislation/.

Koc, A. B. and M. Abdullah (2013). "Performance and NOx emissions of a diesel engine fueled with biodiesel-diesel-water nanoemulsions." Fuel Processing Technology **109**(0): 70-77.

MassDEP (2008). Diesel Engine Retrofits in the Construction Industry: A How To Guide, Massachusetts Department of Environmental Protection

Nealon, S. (2013) Hybrid Not Always Greener.

Testing of hybrid construction vehicles finds a reduction in fuel consumption, but an increase in harmful emissions

Netcen (2004). Non-road Mobile Machinery Usage, Life and Correction Factors.

Ricardo-AEA (2013). Assessment of compliance costs for the proposed GLA NRMM LEZ scheme.

Tsai, J.-H., et al. (2014). "Emission reduction of NOx, PM, PM-carbon, and PAHs from a generator fuelled by biodieselhols." Journal of Hazardous Materials **274**(0): 349-359.

Tsai, J.-H., et al. (2014). "Emissions from a generator fueled by blends of diesel, biodiesel, acetone, and isopropyl alcohol: Analyses of emitted PM, particulate carbon, and PAHs." Science of The Total Environment **466–467**(0): 195-202.

Yilmaz, N., et al. (2014). "Effect of biodiesel–butanol fuel blends on emissions and performance characteristics of a diesel engine." Fuel **135**(0): 46-50.

Zhang, Z.-H. and R. Balasubramanian (2014). "Physicochemical and toxicological characteristics of particulate matter emitted from a non-road diesel engine: Comparative evaluation of biodiesel-diesel and butanol-diesel blends." Journal of Hazardous Materials **264**(0): 395-402.

Impact of fugitive emissions from cement plants

As well as on-site emissions supply, handling and transport of both waste and building materials plays a large part in the construction and demolition industries.

It is well documented that there are negative impacts from cement batching plants where there is not sufficient dust control in place (Schuhmacher, Domingo et al. 2004).

Mineral dust contains high concentrations of many metals known to have toxic effects not only in plants and animals but also in humans (Branquinho, Gaio-Oliveira et al. 2008)

Cement dust can cause ill health by skin contact, eye contact or inhalation. The risk of injury depends on the duration and level of exposure and the individual's sensitivity. Moreover, different cements have different ingredients that can be hazardous causing silicosis, potentially fatal lung diseases and cancer.

High concentrations of fugitive particle emissions from a cement plant may affect the health and property of homeowners living in close proximity to the plant, often leading to complaints. This include specific problems relating to odours, blasting, noise, respiratory problems and corrosive dust on cars (Abdul-Wahab 2006).

Particle emissions may be released from rotary kiln exhaust, and other operations in cement manufacture such as milling, storage and on-site transportation. Much of the processes are carried out on dry materials as this is more energy efficient but can lead to higher emissions of fugitive dust.

There is also a considerable amount of dust emitted from handling, spillage and leakages.

The raw materials and fuel contain metal elements and their concentrations can vary widely. Non-volatile heavy metal compounds (arsenic, chromium, copper, nickel and vanadium) remain within the process and exit the kiln as part of the clinker. Semi-volatile metals (cadmium, lead, selenium and zinc) are partly volatised in the hotter parts of the kiln and condense on raw materials in the cooler parts of the kiln.

Process fugitive emission sources are normally captured by a ventilation system and the dust is collected by fabric filters (Neil R Passant 2002)

References

(DfT), D. f. T. (2014). "Outline of Non-Road Mobile Machinery (NRMM) Emissions Regulations." from http://www.dft.gov.uk/vca/enforcement/non-road-mobile-mach.asp.

(EPA), U. E. P. A. (2002). A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions.

(EPA), U. E. P. A. (2004). Summary and Analysis of Comments: Control of Emissions from Nonroad Diesel Engines.

(EPA), U. S. E. P. A. (2006). "Reducing Emissions from Construction Equipment." from http://www.epa.gov/region1/eco/gb3/pdfs/GB3_ConstructionEmissions.pdf.

(EPA), U. S. E. P. A. (2007). Cleaner Diesels: Low Cost Ways to Reduce Emissions from Construction Equipment.

Abdul-Wahab, S. A. (2006). "Impact of fugitive dust emissions from cement plants on nearby communities." Ecological Modelling **195**(3–4): 338-348.

Amato, F., et al. (2009). "Evaluating urban PM10 pollution benefit induced by street cleaning activities." Atmospheric Environment **43**(29): 4472-4480.

Amato, F., et al. (2010). "A review on the effectiveness of street sweeping, washing and dust suppressants as urban PM control methods." Science of The Total Environment **408**(16): 3070-3084.

Ben Barratt, D. C., Gary Fuller, David Green and Anja Tremper (2012). Evaluation of the impact of dust suppressant application on ambient PM10 concentrations in London.

Branquinho, C., et al. (2008). "Biomonitoring spatial and temporal impact of atmospheric dust from a cement industry." Environmental Pollution **151**(2): 292-299.

Chang, Y.-M., et al. (2005). "Effectiveness of street sweeping and washing for controlling ambient TSP." Atmospheric Environment **39**(10): 1891-1902.

Commission, E. (2013). Stakeholder Consultation on the revision of the Directive 97/68/EC on emissions from nonroad mobile machinery engines.

Deakin, D. U. (2011). Targeted Application of Calcium Magnesium Acetate (CMA) Pilot Study Monitoring Report.

DieselForum.org (2013). CLEAN DIESEL TECHNOLOGY FOR OFF-ROAD ENGINES AND EQUIPMENT: TIER 4 AND MORE.

Dieter Vandenbroucke, A. V. H., Laurent Francx (2010). Study in View of the Revision of Directive 97/68/EC on Non-Road Mobile Machinery (NRMM) (An Emission Inventory and Impact Assessment), Arcadis.

EurActiv.com (2014) Draft EU road machinery laws omits PM limit and emissions count.

FireFly (2014) HYBRID POWER GENERATORS FOR CONSTRUCTION, INFRASTRUCTURE AND PLANT HIRE.

GenCat (2008) Case Study CO, HC & PM Emission Reduction - Perkins 4016TAG2.

GenCat (2013) How to reduce black smoke and carbon emissions from diesel engines - GenCat Diesel Particulate Filters.

Gillies, J. A., et al. (2005). "Effect of vehicle characteristics on unpaved road dust emissions." Atmospheric Environment **39**(13): 2341-2347.

GLA (2014). The Control of Dust and Emissions during Construction and Demolition, Greater London Authority.

GLA (2014). "Mayor's new scheme to tackle old, polluting construction machinery & boost air quality." from http://www.london.gov.uk/media/mayor-press-releases/2014/08/mayor-s-new-scheme-to-tackle-old-polluting-construction.

Grayson, W. (2013) Study: Hybrid construction equipment emits more harmful pollutants than diesel-only machines

Hartley, G. (2014). Constructing a cleaner future. G. Hartley, Energy Savings Trust.

Jackson, T. (2014) How 3 diesel-electric and hybrid construction machines are waging war on wasted energy

Johnson, D. K. C. (2013). Hybrid Off-Road Equipment In-Use Emissions Evaluation.

Karanasiou, A., et al. (2011). "Road dust contribution to PM levels – Evaluation of the effectiveness of street washing activities by means of Positive Matrix Factorization." Atmospheric Environment **45**(13): 2193-2201.

Karanasiou, A., et al. (2012). "Variation of PM2.5 concentrations in relation to street washing activities." Atmospheric Environment **54**(0): 465-469.

Kent, M. (2014). "Emission legislation on the horizon." Retrieved 17/9/2014, 2014, from http://www.adjacentgovernment.co.uk/housing-building-construction-planning-news/emission-legislation/.

Koc, A. B. and M. Abdullah (2013). "Performance and NOx emissions of a diesel engine fueled with biodiesel-diesel-water nanoemulsions." Fuel Processing Technology **109**(0): 70-77.

MassDEP (2008). Diesel Engine Retrofits in the Construction Industry: A How To Guide, Massachusetts Department of Environmental Protection

Nealon, S. (2013) Hybrid Not Always Greener.

Testing of hybrid construction vehicles finds a reduction in fuel consumption, but an increase in harmful emissions

Neil R Passant, M. P., Howard J Rudd, David W Scott, Ian Marlowe and John D Watterson (2002). UK Particulate and heavy metal emissions from industrial processes, DEFRA.

Netcen (2004). Non-road Mobile Machinery Usage, Life and Correction Factors.

Norman, M. and C. Johansson (2006). "Studies of some measures to reduce road dust emissions from paved roads in Scandinavia." Atmospheric Environment **40**(32): 6154-6164.

Project, C. E. L. (2012). CMA+ Instuction Manual 1.1 for the reduction of fine-dust (PM) pollution through the application of a liquid 'fine-dust glue' (Calcium Magnesium Acetate)

Ricardo-AEA (2013). Assessment of compliance costs for the proposed GLA NRMM LEZ scheme.

Schuhmacher, M., et al. (2004). "Pollutants emitted by a cement plant: health risks for the population living in the neighborhood." Environmental Research **95**(2): 198-206.

Tsai, J.-H., et al. (2014). "Emission reduction of NOx, PM, PM-carbon, and PAHs from a generator fuelled by biodieselhols." Journal of Hazardous Materials **274**(0): 349-359.

Tsai, J.-H., et al. (2014). "Emissions from a generator fueled by blends of diesel, biodiesel, acetone, and isopropyl alcohol: Analyses of emitted PM, particulate carbon, and PAHs." Science of The Total Environment **466–467**(0): 195-202.

Yilmaz, N., et al. (2014). "Effect of biodiesel–butanol fuel blends on emissions and performance characteristics of a diesel engine." Fuel **135**(0): 46-50.

Zhang, Z.-H. and R. Balasubramanian (2014). "Physicochemical and toxicological characteristics of particulate matter emitted from a non-road diesel engine: Comparative evaluation of biodiesel-diesel and butanol-diesel blends." Journal of Hazardous Materials **264**(0): 395-402.