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TRANSPORTATION CENTER
and OUTREACH CENTER

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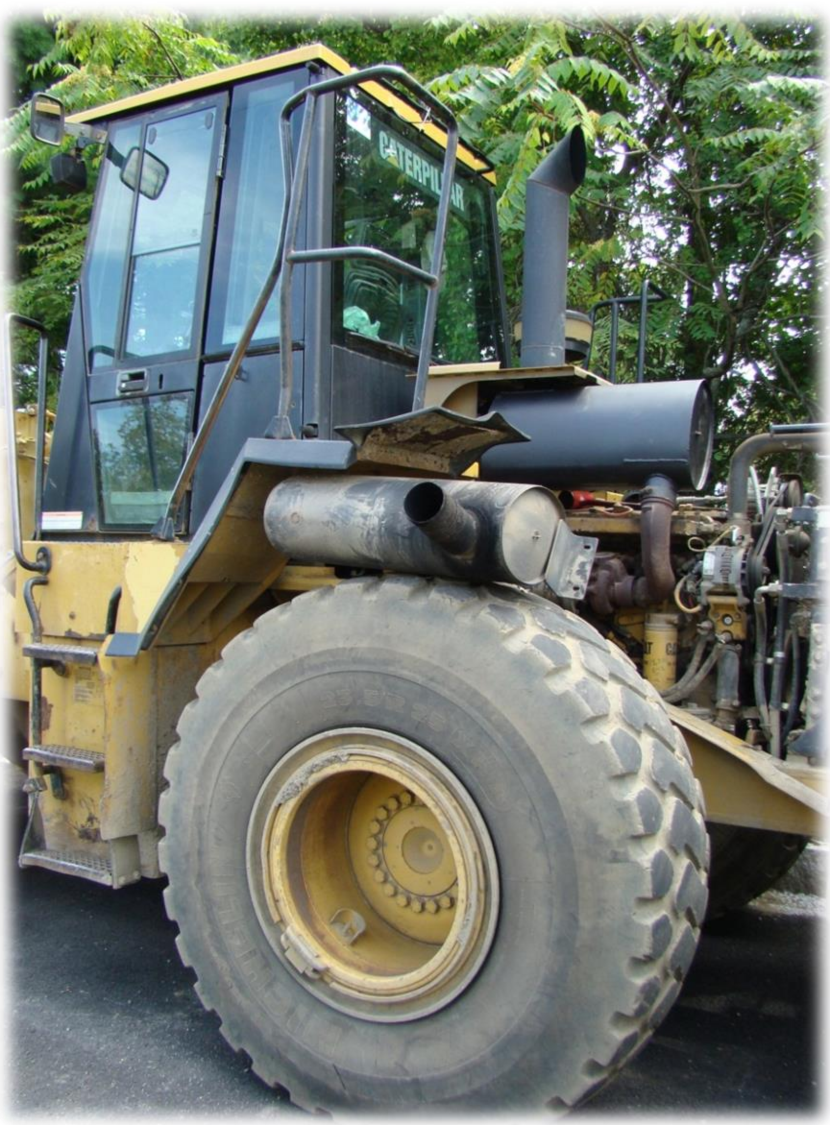
Diesel Emission Reduction in Construction Equipment

Rhode Island Department of Transportation



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Acronym List

BHP	Brake Horsepower
CARB	California Air Resources Board
CCV	Closed Crankcase Ventilation [Filter]
CO	Carbon Monoxide
CO2	Carbon Dioxide
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particulate Filter
EFN	Engine Family Name/Number
EPA	U.S. Environmental Protection Agency
FTF	Flow-Through Filter
HP	Horsepower
HC	Hydrocarbons
NOx	Nitrogen Oxides
OEM	Original Equipment Manufacturer
PCFE	Particle Count Filtration Efficiency
PM	Particulate Matter
PM_{10}	Particulate Matter < 10 microns in diameter
$PM_{2.5}$	Particulate Matter < 2.5 microns in diameter
ppm	Parts per Million
RFP	Request for Proposal
RIDEM	Rhode Island Department of Environmental Management
RIDOT	Rhode Island Department of Transportation
SOx	Sulfur Oxides
ULSD	Ultra Low Sulfur Diesel
URI	University of Rhode Island
URI CELS	University of Rhode Island College of the Environment and Life Sciences
URI TC	University of Rhode Island Transportation Center
VERT	Verification of Emission Reduction Technologies
VIN	Vehicle Identification Number

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Executive Summary

The state of Rhode Island general law "The Diesel Emission Reduction Act" required a pilot project be undertaken to gain a better understanding of the impact of this legislative act.

The Rhode Island Department of Transportation (RIDOT) was named the responsible party to commission and fund the pilot project. The pilot project was funded under a force account as part of the overall construction budget for the Waterfront Drive Project from Warren Avenue to Dexter Street in East Providence, RI. The force account was established by internal RIDOT engineers based upon best known practices. The force account established equated to 3.1% of the overall estimated construction cost of this phase of the project.

The pilot project was granted to the University of Rhode Island (URI). The focus was to gain insight into the retrofit process and to determine the most appropriate level of emission control and best practices needed to reduce diesel emissions on Public Works Projects. The outcomes have been utilized to better define the retrofit process for off road diesel construction equipment and to develop a road map for the State of Rhode Island to outline the most feasible and cost effective approach for reducing diesel particulate matter (PM) in the legacy fleet of construction equipment.

In summary, over the past two construction seasons 2011 and 2012:

1. 14 pieces of construction equipment were tested, and retrofitted.
2. An overall 20% reduction in opacity was verified by URI.
3. An overall 40% reduction in $PM_{2.5}$ was guaranteed by the retrofit manufacturer.

These outcomes have been utilized to develop a final report to the University of Rhode Island Transportation Center, the University of Rhode Island College of the Environment and Life Sciences, Rhode Island Department of Transportation, Rhode Island Department of Environmental Management and the Rhode Island General Assembly. This report includes:

1. Our methods, procedures, and experiences throughout the pilot project.
2. Recommended best practices for the most efficient, cost effective approach to Diesel Emission Reduction in Rhode Island's off road construction fleet while taking into consideration the difficulties faced by the construction industry throughout this process.
3. A road map to detail the technical process to reduce diesel PM in the legacy fleet of construction equipment.

4. Information outlining what other states in our region have done.
5. The overall impact of the legislative act on the State of Rhode Island.

As we began to research the different efficiencies of the technologies and the costs associated with each in order to develop the road map, two things became clear. The cost effectiveness of each of the three common emission control device types was fairly comparable, and there are many variables other than just cost and emission reduction efficiency that are important to consider throughout the retrofit process.

Two important characteristics were observed from the bids received from the various vendors. First, as horsepower increases the cost per percent reduction also increases. Simply stated, this means that it will cost more to achieve the same percent emission reduction on vehicles with more horsepower. This is logical and expected; it takes more material to construct a larger retrofit device that is appropriately sized to a larger engine. It is also important to keep in mind that larger engines will usually burn more fuel, thus emitting a greater overall quantity of pollution than a smaller engine that has the same opacity value or is classified in the same emissions Tier as the larger engine. Therefore, this higher cost is actually justified by the removal of a greater quantity of pollutants. Second, as the percent emission reduction increases across the various technology types, from Diesel Oxidation Catalyst (DOC) to Flow-Through Filter (FTF) to Diesel Particulate Filter (DPF), there is very little change in cost per percent reduction. This means that even though the total dollars spent needs to increase in order to increase the percent emission reduction, this increase is mostly linear, indicating that it does not cost disproportionately more to install a DPF with a high pollutant removal percentage than it does to install a DOC with a lower pollutant removal percentage. In fact, based on the price quotes that we received for the various technologies, FTFs, a device with a mid-level emission removal percentage shows the best trend towards having the overall lowest cost per percent reduction of the three retrofit device types. Out of all 14 pieces of the equipment assigned to this project, FTFs consistently had either the lowest cost per percent reduction or were a very close second, only costing more than the lowest by a few dollars per percent reduction. Because of this characteristic, along with the lack of significant installation prerequisites and ease of installation of a typical FTF, this retrofit device earns the classification as the most cost effective emission reduction technology examined by this project.

Chapter 1: The Importance of Diesel Emission Reduction in Off Road Construction Equipment

The State of Rhode Island legislature has required the Rhode Island Department of Transportation, (RIDOT) to commission a study to determine the level of emissions and best available practices to reduce diesel emission of construction equipment utilized on Public Works Projects.

The primary focus of the diesel emission reduction pilot project commissioned by RIDOT and administered by the University of Rhode Island, (URI) is to gain insight into the most cost effective approach to reducing diesel particulate matter in the legacy fleet of construction equipment in the State of Rhode Island.

Retrofit Objectives

1. To data log for percent opacity and duty cycle temperature as guidance to choosing appropriate emission technology for diesel construction equipment.
2. To gain experience with procurement, installation, maintenance and operation of pollution control technologies for both on and off road diesel powered equipment.
3. To evaluate the performance of diesel emission technologies and identify potential problems, hidden costs, unforeseen complications and additional benefits from the use of various types of retrofit technology.
4. To help identify best management practices to be proposed and adopted by RIDOT in its operations and standard contract specifications.

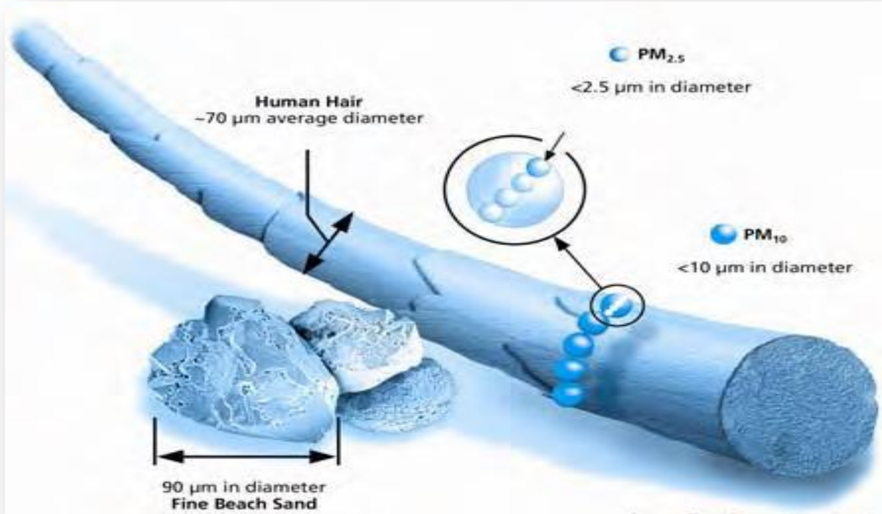
Health Concerns

Diesel truck and equipment engine retrofits focus on reducing pollution from diesel particulate matter (PM) in order to protect the health of nearby workers and citizens.

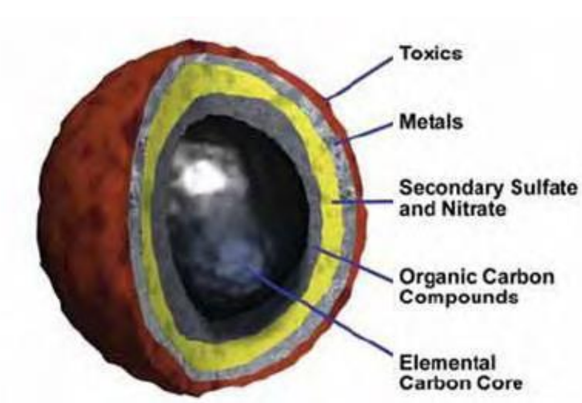
This is critical to the North East region of the country due to the documented 30% higher incidence of upper respiratory issues within the population of the region. The region is subject to global weather patterns which bring pollution along with the weather from west to east into the northeast region.

For nearly four decades, focused efforts have been underway to reduce emissions from mobile sources, both on road trucks and off road equipment and engines. While most of the early efforts centered on the on road gasoline cars, significant efforts have been enacted over the past 15-20 years to reduce emissions from heavy-duty diesel trucks, and off road diesel engines. In addition to gaseous pollutants such as nitrogen oxides (NOx) and non-methane hydrocarbons (NMHC), the Environmental Protection Agency (EPA) has implemented more stringent emission standards for particulate matter (PM) emissions in a phased approach, taking into account the state of technology at the time.

What is Particulate Matter (PM)?



PM is a generic term used to describe a combination of diverse liquid and solid substances that come from both manmade and natural sources. Diesel PM is generally composed of a carbon soot core with other materials adsorbed on the surface, including hydrocarbons, toxics, metals, and sulfates. Very small PM particles can be easily inhaled and pose a significant health risk to humans. Reducing PM pollution from all sources including diesel engines, will be beneficial for the local community, as well as for workers that are in close proximity to diesel exhaust. PM is often classified according to how large the particles are, with the two primary classifications PM10 (average particle diameter less than 10 microns) and PM2.5 (average particle diameter less than 2.5 microns); the smaller PM2.5 particles are a sub-set of PM10 particles. The PM produced by diesel engines is typically composed mostly of very small particles, with greater than 97 percent of diesel PM mass PM2.5.



A typical human hair, at about 70 microns, is nearly 30 times wider than a PM2.5 particle. PM2.5 presents a serious human health risk because the particles are small enough to pass through the nose and throat and lodge deep within the lungs when inhaled. The smallest particles may also enter the bloodstream directly through the lungs.

Health Effects of Diesel PM

A person’s exposure to diesel PM2.5 is referred to as either short-term (from a few hours to several days), or long-term (from one to many years). An individual’s frequency and magnitude of exposure, as well as their general state of health and age, all influence the effects of breathing diesel PM2.5. Children are at increased risk from PM exposure because their lungs are still developing, they breathe more rapidly than adults, and they are generally more active than adults. Short-term exposure is most harmful for people with existing health problems and can exacerbate existing lung disease; cause asthma attacks, coughing and acute bronchitis; increase the severity of asthma attacks; and may increase susceptibility to respiratory infections. Short-term PM exposure has also been linked to heart attacks and arrhythmias in people with existing heart disease. Long-term exposure to PM occurs over a number of years and results from living or working in environments where there is sustained exposure to PM. This kind of long-term exposure has been associated with various pulmonary and cardiovascular disease such as reduced lung function, the development of chronic bronchitis and cardiovascular diseases and even premature death. In addition, EPA has identified diesel $PM_{2.5}$ as a probable carcinogen due to the demonstrated link between long-term exposure and increased risk of death from lung cancer. The agency has also designated many of the hydrocarbons in diesel PM (e.g., benzene and formaldehyde) as toxic hazardous air pollutants and/or carcinogens.

PM Regulations

EPA recognizes that heavy-duty vehicles are noteworthy contributors to poor air quality in many areas of the country, and that concerted efforts to clean them up will provide significant benefits. Controlling emissions from heavy-duty diesel engines has been a particular EPA focus. Over the last 20 years EPA has enacted a series of regulations, for

both on and off road diesel engines, that require new engines to be lower-emitting.

The result is that on road engines today are 96 percent cleaner than ones produced 15 years ago, while off road engines are approximately 50 percent cleaner. Although new engines are cleaner, there are still a significant number of older engines in use. Because of the long useful life of these diesel engines in both on and off road applications these older engines can benefit from a diesel PM targeted retrofit strategy to lower in-use emissions. To date, the only retrofit programs other than those targeted to urban buses have been voluntary; many are being spearheaded by federal, state, and local agencies similar to Rhode Island.

Reducing Diesel PM – *What Can Be Done?*

Diesel PM reduction strategies fall into one of four general categories as listed below:

1. **Reduce Idling:** Decrease engine idling to reduce emissions and save fuel (Rhode Island Anti-Idling Legislation).

2. **Replace/Repower/Rebuild:** Retire vehicles or engines "early", and replace them with new, cleaner engines, or rebuild and upgrade engines to incorporate cleaner technologies.

3. **Retrofit:** Install retrofit equipment or a muffler replacement device to reduce emissions. These include Diesel Oxidation Catalysts (DOCs), Flow-Through Filters (FTFs), Diesel Particulate Filters (DPFs), and Closed Crankcase Filters (CCVs), which are discussed in Chapter 2.

4. **Refuel:** Use a cleaner diesel fuel, Ultra Low Sulfur Diesel (ULSD), biofuels such as Biodiesel and Ethanol, or fuel born catalysts.

Except for retrofitting, these are the same approaches that have been taken to clean up gasoline-powered cars and light trucks. Methods for implementing these strategies include grant programs, enforcement programs, regulations, voluntary initiatives, as well as contract and permit requirements. Many municipalities and states, including Rhode Island, are currently exploring methods to require contractors on state and/or federally funded projects to reduce in use diesel emissions through retrofit or engine upgrade/replacement programs. In Connecticut, the DOT successfully implemented a contract-based diesel PM reduction strategy for contractors' diesel equipment and trucks.

What Has Been Done

A great number of retrofit projects have been implemented throughout the U.S., mostly on a voluntary basis, and many states are currently considering efforts to require diesel PM emission reduction retrofits for select categories of vehicles. Following is a non-exhaustive description of some programs that have occurred in the wider region around Rhode Island.

Legislative Initiatives

In September of 2005 New Jersey passed N.J.A.C. 7:27-14. This law prevents diesel-powered motor vehicles from idling for more than 3 consecutive minutes, and includes, stiff penalties for non-compliance. This law also requires all school buses in New Jersey, public and private, to be fitted with closed crank case ventilator controls. This technology prevents exhaust emissions from entering the bus cabin, where children could breathe it in. The law also states that owners of transit buses, garbage trucks, and on/off road construction vehicles must provide the state with retrofit Compliance Plans. These Compliance Plans detail how each diesel vehicle will be retrofitted and with what technology. Installation of retrofit equipment will be phased in over a ten year period. The cost for each retrofit is being reimbursed. On December 22, 2003, New York City adopted Local Law 77. This law mandates the use of Ultra Low Sulfur Diesel (ULSD) fuel and best available technology (BAT) to reduce emissions from off road equipment used in city construction. This law requires ULSD fuel and BAT to be used for heavy-duty diesel equipment above 50 horsepower that are used on all city-funded construction contracts. The law's requirements were phased in starting in June of 2004. It first applied to projects in lower Manhattan and later expanded to include all projects city-wide by December 2004. This law is in effect for equipment owned, leased and operated by any city agency.

Real World Deployments

The Port Authority of New York and New Jersey implemented advanced diesel particulate emission controls on construction equipment at the World Trade Center. The initiative began prior to Local Law 77, and started with the retrofit of two Caterpillar 966G front end loaders with DPF. At the same time a fuel switch to ULSD was implemented for the retrofit vehicles. As a follow-on to the project, the Port Authority developed policies that require all contractors using diesel-powered equipment at the World Trade Center site to use best available PM emission controls. Boston's Central Artery/Tunnel project was under construction for over 15 years beginning in 1991. Construction required the continuous use of several hundred pieces of construction equipment for excavation, underpinning, roadway and tunnel construction, and street surfacing. To minimize the impact of this equipment on the air quality of surrounding Boston neighborhoods, the project sponsor, the Massachusetts Turnpike Authority, in collaboration with other government and private organizations, implemented a construction equipment retrofit program beginning in 1998. This was the first large-scale construction equipment retrofit program undertaken, and by the time the Big Dig was complete over 200 pieces of construction equipment had been retrofitted with DOCs.

The Connecticut DOT began the New Haven Harbor Corridor Crossing Improvement Program in 2002. This is a major road project along seven miles of the I-95 corridor in southern Connecticut. The project sponsor, the Connecticut Department of Transportation, began planning for construction equipment retrofits in October 2000, one year before the first contract was bid. The Connecticut Clean Air Construction Initiative was developed with the participation of the Connecticut Construction Industries Association and other groups.

Under this program contractors were required to either retrofit their equipment with DOCs or use alternative clean fuels. These requirements were put into the contract bid specifications so that contractors could plan for the costs and include them in their bids.

To date all contractors have chosen the retrofit option. Six different contractors have already installed DOCs on nearly 100 pieces of equipment used on the project.

The State of Rhode Island introduced a General Law entitled "The Diesel Emission Reduction Act", (2010 – S2440 Sub A) on February 11, 2010 [Appendix B]. This legislation requires that a pilot project study commissioned by RIDOT be conducted, with reporting of the findings submitted to the Rhode Island General Assembly no later than sixty (60) days after project completion. Effective January 1, 2013, all "Public Works Contracts" issued by RIDOT, funded partly or in whole by federal monies having a cost of $5,000,000.00 or more shall include provisions requiring all heavy duty vehicles used in the performance of the contract adhere to the requirements of the law.

The law further requires RIDOT, Public Works Projects to include funding for the retrofit of vehicles working on public works projects that are over 75 HP and on the project site for a minimum of 30 consecutive work days. It is the responsibility of the contractor to submit a vehicle inventory list, testing to determine the type and level of emission control that each vehicle qualifies for.

The Rhode Island Department of Environmental Management, (RIDEM) is required to report annually on the progress of the retrofit projects. The RIDEM is also required to maintain and submit vehicle inventory lists for the equipment which has been retrofitted throughout the prior years.

Chapter 2: Description of Available Retrofit Technologies

In this section, descriptions of the various diesel retrofit technologies used to reduce harmful diesel emissions will be provided. The three types of technologies that were installed and utilized in this project are also the three most common currently in use: diesel oxidation catalysts (DOCs), flow-through filters (FTFs), and diesel particulate filters (DPFs). Another retrofit technology that will be discussed in this section and was considered but not used in this project is known as a Closed Crankcase Ventilation (CCVs) Filtration System. This section will describe how each of these technologies works as well as the applicability, limitations, benefits, maintenance, and longevity of each.

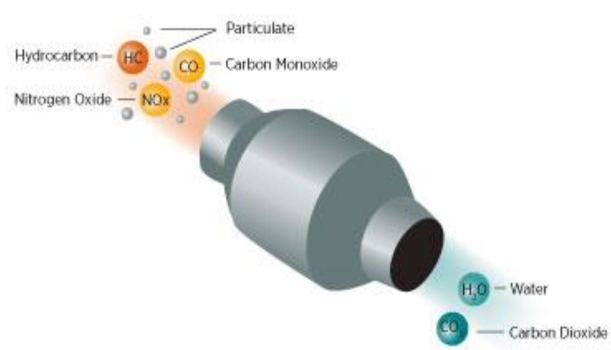
Due to the common use of EPA/CARB "verification" to select or rule out certain types or manufacturers of these devices, verification will be explained and the various verification programs will be outlined along with the benefits and drawbacks of verifying devices.

Related to, and often overlapping with EPA/CARB verification is the topic of manufacturers' warranties and certifications. The warranties and certifications of the retrofits will be discussed, as will the warranties of the vehicles and/or engines in terms of modifications to the equipment, specifically retrofits.

Finally, the process of selecting the appropriate retrofit for a certain vehicle will be briefly summarized with some of the more critical points. This topic is discussed in greater detail in Chapter 4: Methods and Procedures within the "Retrofit Selection, Purchase, and Installation" section.

Diesel Oxidation Catalysts

Diesel Oxidation Catalysts are currently the most common retrofit in use today due to their few installation requirements and ease of installation. Because of this, they can be used on almost any diesel engine. As with FTFs and DPFs, these devices replace the existing muffler and integrate sound attenuation into their overall functionality. In most cases, DOCs can be manufactured to exactly match the existing muffler's dimensions. This is known as a "direct replacement" retrofit, and this term applies to FTFs and DPFs as well, although becomes less common with FTFs and is almost never seen with



DPFs.

From the outside, a DOC will usually look almost identical to the muffler that it is replacing. However, inside is where the magic happens. The inside of the DOC contains a core made of metal or ceramic which the exhaust stream will flow-through via channels or holes. These passageways are coated with a precious metal catalyst such as platinum or palladium that promotes the oxidation of the toxic byproducts of combustion contained within the exhaust stream. The catalyzed chemical oxidation reaction breaks the pollutants down into less harmful compounds and components. The specific reactions encouraged by DOCs include: converting carbon monoxide (CO) to carbon dioxide (CO_2), and hydrocarbons (HC) to water (H_2O) and CO_2, using the oxygen (O2) already in the exhaust stream. These reactions typically result in a reduction of $PM_{2.5}$ by 20-40+%, CO by 15-60% and HC by 50-70%.

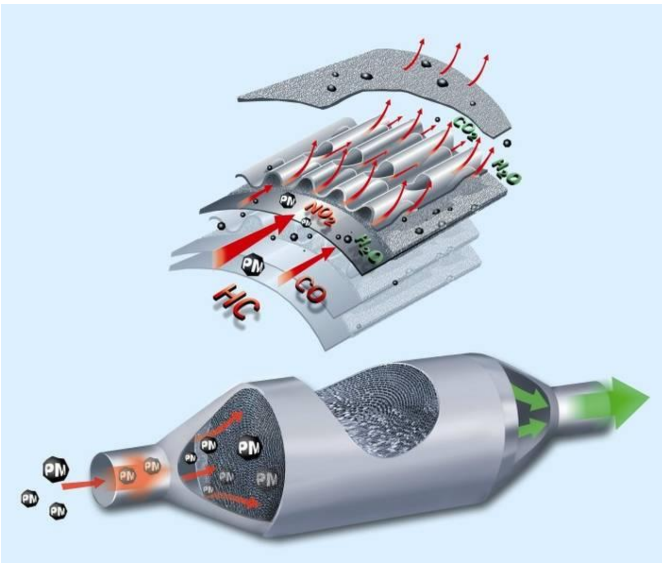
The pre-requisites for the installation of a DOC are very minimal. Common requirements from DOC manufacturers say that the engine on which the DOC is being used must: be operated with a fuel that contains a sulfur content of no more than 15 ppm (ultra-low sulfur diesel fuel); achieve an exhaust temperature of at least 150° C during its duty cycle; be well maintained and not consume lubricating oil at a rate greater than that specified by the engine manufacturer; not be equipped with an oil burning system, and lube oil or other oils may not be mixed with the fuel; not have been originally certified or equipped with a DOC or DPF. Currently, ultra-low sulfur diesel (ULSD) fuel is mandated for use in all construction vehicles both on and off road, so the first requirement should always be met. This temperature requirement is very low, and no heavy-duty diesel vehicle should have any trouble achieving this temperature during its duty cycle. Of the fourteen engines for which we recorded duty cycle temperature data, all of them easily exceeded 150° C during even very short operating periods of less than 30 minutes. The next two requirements only state that the vehicle should be well maintained and in good working condition. This decision should be made on a case-by-case basis, but making the investment to install a DOC on a dilapidated piece of equipment that probably will not last very long before it is decommissioned might not be the best allocation of funds. Altering composition of the exhaust gas caused by burning large amounts of lubricating oil could decrease the effectiveness of or be harmful to the retrofit device. The last requirement is simply indicating that no more than one retrofit device of similar type should be installed on each engine. Therefore, the use of a DOC is usually only precluded by extremely old or poorly maintained vehicles that are likely nearing the end of their life. Every manufacturer will have different requirements and limitations for their devices, and these should be reviewed on a case-by-case basis whenever the installation of a DOC is being considered.

The installation of a DOC is almost always a very simple, straightforward, and relatively quick process. When the DOC is a direct replacement for the muffler, the installation of this device is identical to replacing the muffler: remove the existing muffler, place the DOC in its place, and secure it as you would the muffler itself. There are some cases in which a direct replacement DOC will not be available for a piece of equipment. In these situations there are several possibilities with regards to installation. The best case scenario is that even though the DOC is not a direct replacement, it can still be placed in the same location as the original muffler and use all of the same fasteners to secure it to the vehicle safely. Alternatively, there could be room to place the DOC in the same location as the original muffler, but minor modifications might need to be made to the mounting system in order to be able to safely and securely fasten the DOC to the vehicle. The worst case scenario is that the DOC does not fit in the same location as the original muffler, in which case an alternate location on the vehicle would need to be selected to mount the DOC, and the exhaust piping would need to be re-routed accordingly. This may entail some major modifications to the equipment. However, this scenario will almost never occur with DOCs since the manufacturers of these retrofits have become very proficient at sizing and packaging their devices to either exactly or very closely match the size of the equipment's original muffler. Of the 6 DOCs that were installed on this pilot project, all 6 were direct replacement devices and none of the DOC installations took longer than 1.5 hours from start to finish.

As with many of the other aspects of the retrofitting process, the cost of DOCs vary significantly based mainly on the size of the engine on which they are being installed. As the size and horsepower of the engine increase, the cost of an applicable DOC will usually increase accordingly due to the higher quantity of materials being used (especially the expensive precious metal catalysts) to construct and appropriately size the DOC. At the time of this writing, the average price range for a DOC for the typical construction equipment engine is between $2,000 and $6,000, including installation. Of the bids that we received for the equipment assigned to this project, all of the quotes for DOCs fell between $1,800 and $4,900, including installation.

Flow-Through Filters

Flow-through filters are similar to DOCs in their versatility and applicability, as well as the method of their operation. Like DOCs, FTFs claim few installation requirements and are typically very easy to install. They are also installed in place of the vehicle's existing muffler, meaning that the FTF takes on sound attenuation as one of its capabilities. FTFs can often be designed as direct replacement devices, but the ability to do so is not as common as with DOCs, especially on larger engines. This is due to the different core configuration of the devices, as well as the differing amounts and types of core catalyst materials.



From the outside FTFs will also appear very similar to the original muffler, but may sometimes be a slightly different shape or size. With regard to their operation, the term "flow-through filter" can be somewhat misleading. FTFs normally work on the principle of partial flow deep-bed filtration. Structural elements in the core are designed to direct a portion of the exhaust stream through corrugated metal foils and metal fiber fleece into the filter's adjacent channels. This effectively collects the particles intended for removal from the exhaust stream within the filter, and oxidizes them through the use of a catalytic coating similar to the internal operation of DOCs. However, due to the channeling design of the core, more of the exhaust stream (and thus harmful particles) is exposed to the catalyst and oxidized, resulting in a higher overall reduction in particulate matter and other pollutants than DOCs achieve. Compared to wall-flow filters (the design used commonly in DPFs), FTFs do not need to be regenerated on a regular basis due to the continuous burning of trapped particulate matter. It is also nearly impossible for today's FTFs to become clogged; should too much diesel particulate matter flow-through the filter, the exhaust gas will simply "flow-through" the normal channels in the device without being forced through the metal fiber fleece with the risk of clogging the filter. This virtually eliminates the risks of greatly increased backpressure that can harm the engine or cause vehicle fires. FTFs are also known as particulate catalytic converters or partial flow filters, and they operate on the principle of Continuously Regenerating Trap (CRT). This type of filter is very efficient (usually ~80%) with ultra-fine particles (PM_{10} and smaller), but becomes less efficient with larger particle sizes which brings its overall particulate matter reduction percentage down to an average of 50-70%. Carbon monoxide and harmful hydrocarbons are typically reduced by 80-90%, which almost entirely eliminates the odor from these compounds.

The requirements for installing a modern FTF are minimal and only slightly more restrictive than DOCs. Some common manufacturer requirements for the installation of FTFs state that the engine in the machine on which the FTF is installed must: use fuel with sulfur content less than 500 ppm, and works best with sulfur content less than 15 ppm (ULSD); not have a pre-existing oxidation catalyst or diesel particulate filter; be well maintained and not consume lubricating oil at a rate greater than one quart per 50 engine hours; exhibit engine exhaust temperatures at the filter inlet of at least 280° C for at least two minutes each hour of operation to ensure adequate regeneration. Many of these requirements are similar to the requirements discussed above for DOCs. Since Ultra Low Sulfur Diesel fuel (ULSD) is currently mandated for use in all diesel engines (both on and off road applications), this requirement should always be met. Not having a pre-existing DOC or DPF already installed on the vehicle is another standard requirement, and prevents "stacking" retrofit technologies that would likely cause one or all of them to fail prematurely and potentially damage the engine. The requirement that the vehicle not consume excessive lubricating oil is ensuring that the engine is in acceptable operating condition and has been well maintained. The altered composition of the exhaust gas caused by burning large amounts of lubricating oil could decrease the effectiveness of or be harmful to the retrofit device. The temperature requirements for FTFs are somewhat more stringent than those for DOCs, but is still relatively easily met on many diesel engines, especially larger ones found in construction equipment. Even the smallest of the engines that we data logged were able to meet this requirement. Based on these requirements, FTFs are almost as versatile as DOCs and can be installed on almost any vehicle that a DOC could go on. Every manufacturer will have different requirements and limitations for their devices, and these should be reviewed on a case-by-case basis whenever the installation of a FTF is being considered.

The installation of an FTF can be as straightforward as a simple muffler replacement or in rare cases involve complicated, costly, and time consuming custom mounting and re-routing of the exhaust piping. When the FTF is a direct replacement for the muffler, the installation of the device is identical to replacing the muffler: remove the existing muffler, place the FTF in its place, and secure it as you would the muffler itself. The only exception to this is that sometimes the FTF might require reinforcement to the existing muffler mounting system, as they are can sometimes be considerably heavier than the original muffler. If a direct replacement FTF is not able to be procured for a certain vehicle, it may still be able to be placed in the same location as the original muffler if there is enough extra room to accommodate it. In this case, only minor modifications to the mounting system will be needed. If there is not adequate room, a new location must be determined in which to house the FTF. This will require the re-routing of the exhaust piping leading into and leaving the FTF. Requiring a non-direct replacement FTF will be slightly more likely of an occurrence than with DOCs, but still should not be encountered very often. Of the 7 FTFs that were installed on this pilot project, 5 were direct replacement devices and the FTF installations took between 30 minutes and 4 hours from start to finish depending on complexity.

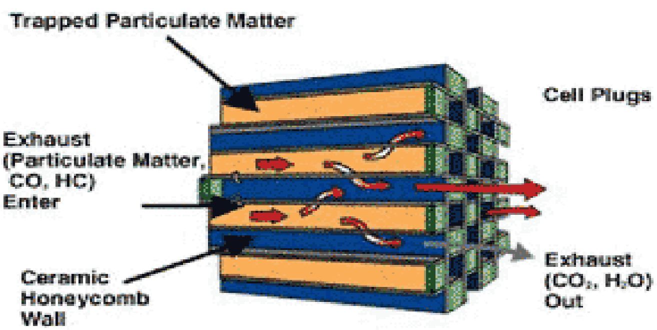
Similar to DOCs, modern FTFs generally require no regular maintenance once installed. They are nearly impossible to clog and do not accumulate soot particles, meaning that from a maintenance perspective they operate just like a conventional DOC. They also usually come packaged within a stainless steel can and will be more durable than a standard steel muffler. FTFs are usually rated to last for at least 5 years and maintain the effectiveness of their catalyst for over 10,000 hours of operation even in heavily used equipment.

The costs associated with FTFs, as with DOCs and other aspects of the retrofitting process, are dependent on many factors, mainly the size of the engine with which they are being installed. As the size and horsepower of the engine increase, the cost of an applicable FTF will usually increase accordingly due to the higher quantity of materials being used (especially the expensive precious metal catalysts) to construct and appropriately size the FTF. At the time of this writing, the average price range for an FTF for the typical construction equipment engine is between $5,000 and $15,000, including installation. Of the bids that we received for the equipment assigned to this project, all of the quotes for FTFs fell between $3,700 and $13,500, including installation.

Diesel Particulate Filters

Diesel Particulate Filters offer the highest emission reduction of all of the common diesel emission retrofit devices. Along with this increased reduction however, comes an increase in cost, physical size of the units, and installation complexity. DPFs will replace the vehicle's muffler just like a DOC or FTF would, but they are much larger in size and will not be offered as direct replacements to the existing muffler. There are two main types of DPF: active regeneration and passive regeneration, although hybrid DPFs are emerging that are a combination of both the active and passive systems. Passive DPFs operate using only the exhaust temperatures generated by the engine, while active DPFs utilize an afterburner system to artificially achieve the necessary temperature requirements.

Externally, DPFs will look like a larger version of a DOC or FTF, although usually with a less uniformly cylindrical shape and the addition of some ports used for monitoring temperatures and backpressure.



Both passive and active DPFs employ a porous filter to physically remove particulate matter from the exhaust stream. Both may also employ a catalyst coating, either on the filter or on a separate core in addition to the filter, which is designed to oxidize pollutants in the exhaust gas exactly as a DOC would. The applicability of DPFs is somewhat limited by the exhaust temperature requirements of passive DPFs. This requirement can be eliminated by the use of an active DPF, but other limitations still remain such as size of the retrofit, cost of the retrofit, and often very heavy modification of the vehicle during the installation of the retrofit. All variations of DPFs will typically reduce $PM_{2.5}$ by at least 85%, along with reducing both carbon monoxide and hydrocarbons by 75-95%.

Passive DPFs will combine their porous ceramic, sintered metal, or silicon carbide filter with a catalytic coating in order to achieve their emission reduction. Some passive DPFs will have the catalyst applied directly to the filter itself, while others will utilize a separate catalyst core similar to those used in either DOCs or FTFs. In either case, the exhaust gases are forced to pass through the filter and come into contact with the catalyst. The filter will physically trap the particulate matter in the exhaust, and the catalyst will encourage the oxidation of the captured PM at the appropriate temperatures. As with DOCs and FTFs, the catalyst will also oxidize other compounds such as carbon monoxide and hydrocarbons. In order to successfully oxidize the necessary quantity of collected PM to keep the filter from clogging, a minimum exhaust temperature must be met for a certain percentage of the vehicle's operating time. This is the primary factor that will exclude vehicles from being able to have a passive DPF installed on them. This duty cycle temperature requirement varies between DPF manufacturers, but the typical passive DPF will require a minimum exhaust temperature of anywhere from 200-260° C for 40% of the vehicle's operating time, or approximately 320° C for 30% of the vehicle's operating time. This requirement can also increase depending on how "dirty" the engine is pre-retrofit; higher than ~0.1 grams of PM per brake horsepower-hour (g/bhp-hr) often results in higher temperature requirements.

Active DPFs are designed very similarly to passive DPFs in terms of having a porous filter that is often used in conjunction with a catalytic coating.

However, the primary difference is that active DPFs include an afterburner capability designed to artificially raise the exhaust temperature to the level required to activate the catalytic oxidation and/or further combust ("burn off") the PM that is captured in the filter. There are two common methods used to bring the filter's temperature up to the required level: injecting additional diesel fuel into the exhaust stream and the use of an electric heating element. In both of these methods the filter will continuously collect PM, and depending on how much of it is catalyzed or burned off during the vehicle's normal duty cycle, the DPF will need to be "regenerated" every so often in order to manually raise the temperature of the filter. When diesel fuel injection is used, the additional diesel fuel is injected into the exhaust stream after it leaves the engine but prior to it entering the filter. Some active DPFs will do this automatically, while others will indicate to the operator that a regeneration cycle is due and must be started manually with the push of a button. When electric regeneration is used, the vehicle must remain plugged in to an electrical outlet (typically 208/240 volt 20 amp) for at least several hours, usually overnight, in order to regenerate the filter. Typical regeneration intervals are between 30-40 hours of engine operation. Even assuming a generous regeneration interval of once every two weeks, the lack of availability of the necessary electrical infrastructure on most construction sites makes this method unfeasible on most construction equipment. With diesel fuel fired afterburning, the exhaust temperature exiting the stack becomes extremely high, so in most cases the vehicle must be parked in a designated "safe zone" during active regeneration to avoid igniting any trees or brush above or behind the exhaust or injuring any bystanders or workers. Where excessive diesel fuel consumption was a concern in the past on older technology, now active DPFs using diesel fuel injection only consume an additional 2-4% of fuel yearly over normal operation. The elimination of the temperature requirement through the use of active DPFs makes this retrofit technology available on a much wider range of vehicles, but adds certain additional limitations of its own including a considerable price increase.

The increased size of DPFs adds some additional installation challenges beyond the fairly straightforward installations of the typical DOC or FTF. Since DPFs will very rarely fit where the muffler is housed, it is necessary to locate an alternate location on the vehicle at which to install the DPF. The primary considerations for selecting this location include: being careful not to impede the operator's line of sight; minimizing the complexity of the install by attempting to re-route the least amount of exhaust piping; being able to support the added weight of the DPF; and finding someplace safe and secure to prevent the DPF from being knocked off during operation, tampered with, or stolen. Other than these considerations, the installation of a passive DPF is only slightly more complicated than that of a DOC or FTF. The retrofit still replaces the muffler, and performs both emission reduction and sound attenuation duties. In addition to the filter itself, several sensors must be installed in the DPF to monitor exhaust stream temperature before and after the device, a computer "brain" to monitor the readings from these sensors, and a heads-up display somewhere in the cab to alert the operator and maintenance personnel to any issues that the computer might detect via the sensors' readings. Specific to DPFs, moisture buildup can occur within the device. There are several methods of managing moisture that may gather in DPF, regenerative unit, and/or backpressure monitoring system; something along the lines of a condensate trap may also be installed. An active DPF will also involve all of these things during its installation, but will be accompanied by whichever afterburner technology it uses to artificially increase the filter's temperature. In the case of electric regeneration, the heating element should be contained within the can of the DPF, and additional wiring will have to be run to notify the operator when regeneration is needed (usually identical to the sensor and heads-up display of a passive DPF). It is also necessary to wire and install an electrical plug or outlet somewhere on the vehicle that is easily accessible to allow the convenient "plugging in" of the retrofit when regeneration is needed. For diesel fuel fired active DPFs, an extra fuel line must be run to the afterburner portion of the DPF to allow regeneration. There will usually be a button or switch in the cab by the heads-up display to initiate the active regeneration. Other sources have indicated that the average installation times for DPFs is usually between 8-15 hours, but our experience with this project has shown higher installation times. The installation of the passive DPF on the 2007 Caterpillar 345C excavators assigned to this project took 30 hours to complete, while the active DPF installation on the 2002 Gradall XL 5100 excavator assigned to this project took 40 hours to complete.

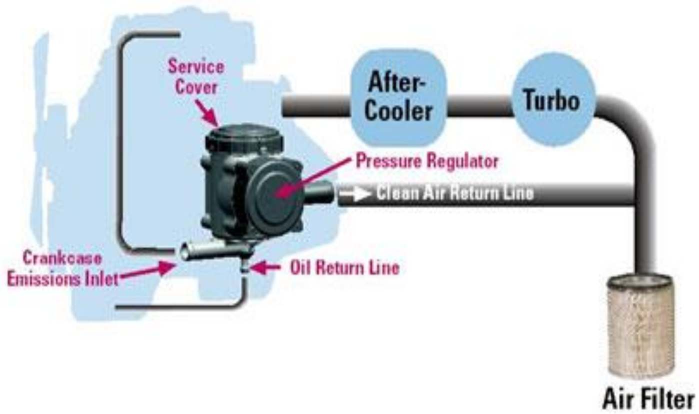
Certain additional maintenance requirements are associated with the ongoing care of a DPF. The stainless steel packaging ensures resistance to harsh environmental effects, but the existence of the wall-flow style filter inside the can is what dictates the extra maintenance. Every manufacturer's maintenance schedule for their DPF will be slightly different, but typically: the engine backpressure should be manually checked every 50 hours of operation; visual inspection of piping, fittings, clamps, and gaskets should be performed every 200 hours of operation to check for leaks in the system; the backpressure transmitter (sensor) should be removed and checked manually to ensure it is functioning properly; and a filter cleaning should be performed every 1,000 hours of operation. A filter cleaning could involve simply vacuuming the filter or blowing it out with low-pressure compressed air if it is only lightly sooted, or by heating the filter in a special oven for 4 hours at 500° C followed by vacuuming or blowing out the filter if it is heavily sooted. The average fee for a cleaning such as this would be in the range of $200-400 per filter. The filters are designed to be easily removable from the DPF can, so removal should take no longer than 30 minutes. Both passive and active DPFs should see about the same lifespan as a DOC or FTF, lasting at least 5 years or 10,000 hours.

Obviously, since a much higher percent reduction of diesel emissions is achieved with DPFs, their cost is also greatly increased over that of a DOC or FTF. This increased cost is seen both in the price of the retrofit itself as well as higher labor costs for a more complex and time consuming installation process. Prices will also increase relative to increased engine size and horsepower, but we did not see a significant difference in DPF prices in the 100-200 HP range. It is likely that this means that the smallest DPF produced by that particular manufacturer was sized for a ~200 HP engine, but is able to be used on smaller engines as well. This is not uncommon, since there is not as much demand for DPFs on the smaller vehicles and engines. In fact it often becomes more difficult to install DPFs on smaller vehicles due to space constraints. At the time of this writing, the average price for a passive DPF for the typical construction equipment engine is between $10,000 and $25,000, including installation. The average price for an active DPF for the typical construction equipment engine is between $15,000 and $50,000 for an active DPF, including installation. Of the bids that we received for the equipment assigned to this project, all of the quotes for passive DPFs fell between $10,000 and $27,000. All of the quotes for active DPFs fell between $17,500 and $43,000.

Closed Crankcase Ventilation Systems

While not an emission reduction technology that deals with exhaust emissions, Closed Crankcase Ventilation (CCV) systems instead focus on reducing crankcase emissions. On their own these devices are not given any credits or verification by CARB or the EPA due to the low, and often difficult to quantify, amount of emission reduction they actually achieve. However, they are often used in conjunction and verified with other retrofit technologies such as a DOC in order to elevate the level of overall exhaust emission reduction. They are designed to contain and eliminate the crankcase gases that normally escape through the crankcase vent tube directly into the environment.

Figure 7: Crankcase Ventilation Tubes



A CCV is an engine control system that is designed to capture and filter the exhaust gases that leak by the piston rings in the engine's cylinders into the crankcase. These gases become contaminated with oil, making them very harmful to humans and the environment. The mixed, contaminated emissions then escape through the diesel engine breather into the engine compartment, engine intake system, or simply out into the environment. The purpose of a CCV is to trap and filter these emissions so they are not being discharged directly into the air or passing through only a rudimentary filter. A truly closed crankcase ventilation system should effectively eliminate 100% of crankcase emissions at all times. Probably the most common CCV design today involves the use of a multi-stage filter that will capture the crankcase emissions, then coalesce and return the emitted lube oil to the engine's oil pan. The clean, filtered gases are either vented into the atmosphere or fed into the engine's intake system while regulating and balancing the differential pressures involved in this process. Alone, estimates place the overall emission reduction achieved by a CCV on a vehicle to be around 5%. When they are used in conjunction with a DOC, a combined reduction of up to 40% can be seen. This is due in part to the added benefits of a CCV system such as: reducing fouling in the engine compartment, effectively increasing the efficiency of charge air coolers, radiators, etc.; yielding a cleaner engine environment, keeping the engine compartment and other components cleaner; decreasing the need for related maintenance, resulting in improved vehicle reliability; and reducing the use of oil and thus vehicle operating costs.

Installing a CCV is fairly simple and straightforward in theory, but potential issues can arise during the process if extensive pre-planning is not properly performed. The filter and housing of the CCV system, which is the main component, is small. This component is usually cylindrical and measures approximately 10 inches tall by 6 inches in diameter with an overall width of 7-8 inches, all depending on the size and horsepower of the engine on which it is to be installed. Difficulties arise when taking into account the additional filter removal clearance requirement of 2-4 inches, the often difficult to achieve 18-20 inch vertical drop requirement from the bottom of the CCV for the oil being returned via the drain at the bottom of the filter housing, as well as the requirement that the CCV must be mounted level with or higher than the engine. Especially on construction equipment that may already have a very tight engine compartment configuration, finding a location under the hood to mount such a device that meets all of the installation requirements can prove very difficult. In addition, the method of returning the oil to the oil pan can add complications as well. The most common methods involve utilizing an unused auxiliary engine dipstick boss, or modifying the engine to add a return oil inlet to the existing dipstick boss or adding some other access to the crankcase. This could potentially constitute significant engine modification if an unused dipstick boss is not available. Since they are usually installed along with a DOC, the operating criteria stated for DOCs will also apply to CCVs installed with DOCs.

A CCV system will require almost no regular maintenance once it has been installed. The only regular maintenance operation that should have to be performed on these devices is inspecting the filters regularly and replacing the filter cartridges every year or 1,000 engine hours or if the filter becomes clogged prematurely, whichever occurs first. A built-in pressure relief valve will allow the crankcase gases to bypass the filter and vent to the atmosphere should the device become clogged so that no harm is done to the engine before the filter can be changed.

Following the trend of lower cost equating to lower emission reduction, CCVs are the least expensive of the emission reduction devices discussed by this publication. Also, due to their nearly universal design and wide range of engine size applicability, the pricing is very consistent. For example, standard CCV sizing would occur in ranges such as: under 40 horsepower, under 400 horsepower, under 800 horsepower, and up from there. There are of course other considerations, but selecting a CCV system is generally much easier than finding an applicable DOC, FTF, or DPF. At the time of this writing, the average price for a CCV system for the typical construction equipment engine is between $800 and $3,000. Of the CCV bids that we received for the equipment assigned to this project (ranging from 105 HP to 593 HP), all of the quotes were for the same model CCV and were priced at just over $1,200 per unit, including installation.

Retrofit Technology Verification Programs

Among the most prevalent retrofit technology verification programs are those created by the United States Environmental Protection Agency (EPA), the California Environmental Protection Agency Air Resources Board (CARB), and the international Verification of Emission Reduction Technologies (VERT). The goals of all three are similar: to evaluate the performance, durability, and any malfunctions or shortcomings of various emission reduction devices in order to "verify" their operability and provide customers of these devices with assurances that the technology will perform as advertised and as expected. The manufacturers of these technologies must apply to have their devices verified through testing and technical review which ensures real emission reductions along with the durability and compatibility of that emission control system. When comparing the verification procedures, it is noted that CARB's process is more stringent than EPA's, and VERT's is stronger and more thorough than either of the other two as well as being less costly to perform, but is not as commonly used in the United States and only focuses on DPF technologies. EPA and CARB also have a reciprocity agreement that enables many of the technologies to be cross-verified as long as they achieve verification under one program or the other. It is not within in the scope of this report to go into great detail regarding the specific testing procedures, but it is important to be aware of these programs' existence, benefits, and shortcomings when purchasing a retrofit device. A more in-depth look at the comparison of these three verification procedures and requirements is shown in Appendix C.

For EPA verification, the manufacturer must specify the type of technology being verified, the applicability including intended use (highway, off road, marine, etc.), and the type of engines on which the technology will fit (often using Engine Family Numbers). Under CARB verification, the same information is gathered, but Engine Family Numbers (EFNs) are relied upon more heavily to delineate the applicability of the verified retrofits with existing engines. CARB verification also separates verified technologies into various levels of reduction: Level 0 is a diesel emission control strategy that reduces emission of PM by less than 25% but reduces emission of NOx by at least 25%; Level 1 reduces emission of PM by greater than 25%; Level 2 reduces emission of PM by greater than 50%; and Level 3 reduces emission of PM by greater than 85%, or down to a level of less than 0.01 g/bhp-hr. Much of the same information is collected with VERT verification, and they also categorize their verified technologies based on the filtration rate for solid particles: technologies from the year 2000 and later that achieve a solid particle reduction average of ≥95% throughout the particle size range of 20-300 nm when new, and ≥90% after 2,000 hours of use earn a Particle Count Filtration Efficiency (PCFE) designation of "A"; technologies from the year 2007 and later that achieve ≥97% when new and ≥97% after 2,000 hours of use earn a PCFE designation of "B"; and technologies from the year 2013 and later that achieve ≥99% when new and ≥99% after 2,000 hours of use earn a PCFE designation of "C".

The programs listed above are all voluntary, but aid manufacturers in assuring their customers of the effectiveness and reliability of their products. It is for this increased assurance that many mandatory diesel engine retrofit programs make verification (most often EPA/CARB) a prerequisite for any retrofit device that will be included as part of the mandatory retrofit program. This is good in the sense that requiring a verified technology takes much of the risk out of the retrofit selection process and standardizes (to a degree) the quantity of reductions being achieved. However, it can also limit the selection of technologies that are available to be purchased. The major flaw in requiring verification of emission reduction technologies is that if a manufacturer cannot afford to put their product through the costly verification process, that product will automatically be excluded from use on any project with a verification requirement even if it is the best and cheapest product on the market. All major emission reduction technology manufacturers will have a written certification, backed by test data and results that will guarantee the performance and longevity of their product. When purchasing emission reduction technologies, it must be decided whether to require EPA/CARB verification, require any major verification, only use verification as a guide, or accept manufacturer certification as adequate assurance.

Performance Guarantees

When dealing with emission reduction technologies it is important to have a guarantee of performance as well as durability and longevity of the equipment being purchased. With the high cost of construction equipment, it is also vital to know that the retrofits being purchased and installed will not harm the vehicles themselves. The warranty requirements for emission reduction technologies mandated by CARB's verification process are shown in the table below.

Table 5. Minimum Warranty Periods

Engine Type	Engine Size	Minimum Warranty Period
On-Road	Light heavy-duty, 70 to 170 hp, Gross Vehicle Weight Rating (GVWR) less than 19,500 lbs.	5 years or 60,000 miles
	Medium heavy-duty, 170 to 250 hp, GVWR from 19,500 lbs. to 33,000 lbs.	5 years or 100,000 miles
	Heavy heavy-duty, exceeds 250 hp, GVWR exceeds 33,000 lbs.	5 years or 150,000 miles
	Heavy heavy-duty, exceeds 250 hp, GVWR exceeds 33,000 lbs., and the truck is: 1. Typically driven over 100,000 miles per year, and 2. Has less than 300,000 miles on the odometer at the time of installation.	2 years, unlimited miles
Off-Road (includes portable engines), Stationary, Marine, Locomotives, TRU, and APU	Under 25 hp, and for constant speed engines rated under 50 hp with rated speeds greater than or equal to 3,000 rpm	3 years or 1,600 hours
	At or above 25 hp and under 50 hp	4 years or 2,600 hours
	At or above 50 hp	5 years or 4,200 hours

In the past, EPA's verification process has mirrored CARB's warranty requirements, but they have stated that they will issue their own table in the future. The warranty requirements for VERT are the same for all on road and off road verified technologies that are deployed, and state that: the technology life expectancy must be greater than 5,000 operating hours; the usable hours between major cleanings must be greater than 2,000 operating hours; maintenance intervals must be greater than 500 operating hours; and a guarantee must be provided for materials and function for greater than 2 years or 1,000 operating hours. When not dealing with verified technologies, it is important to refer to the emission reduction technology manufacturer's warranty and take note of what is and is not included.

For vehicles still under the Original Equipment Manufacturer (OEM) warranty, it is important to consider what effect, if any, installing an emission reduction device will have on this warranty. In some cases, retrofit manufacturers will have already coordinated with the OEMs so that the installation of their devices will not void the vehicle or engine's warranty. It also may depend on who installs the retrofits. For example, an OEM who performs their own work on their vehicles may insist that they be the ones to install the retrofits in order for the vehicle and engine warranty to remain intact. It is always wise to check with the OEM, since there are many different scenarios that could occur. For vehicles which are no longer under any OEM warranty, focus on the warranty terms of the retrofit manufacturer to outline what is and is not covered following installation of the retrofit.

Selecting Appropriate Retrofits

Selecting the appropriate emission reduction technology for a vehicle is unfortunately not a static process, and must be done on a very individualized case-by-case basis for each vehicle that is to be retrofitted. However, there are several factors that are looked at for every vehicle that can make the decision process a bit more standardized and methodical. These factors are things such as: engine horsepower, year the engine was manufactured, the type and model of the vehicle, pollution level, usage amount, temperature duty cycle, retrofits that are or are not available for the vehicle, current policy or legislative requirements dictating which retrofits must be installed or how to decide, and of course available budget. Reviewing these factors during the decision making process, along with placing weight on certain aspects that are more important in each particular situation, will greatly help as a guide towards the most appropriate retrofit. They will also help exclude retrofits that are not possible, not feasible, or not the most appropriate or beneficial for each specific vehicle. More specifics on the process of selecting retrofits for vehicles are discussed in Chapter 4: Methods and Procedures, within the section entitled "Retrofit Selection, Purchase, and Installation".

The first factors that should be looked at when beginning to select retrofits for equipment are the simplest: engine horsepower, the year the engine was manufactured, type and model of vehicle being retrofitted, and the Engine Family Number (EFN). The EFN is arguably the most important single piece of information used throughout the retrofit process, as it is what is most commonly used to evaluate applicability of retrofits to various engines. An EFN is a 12 character alphanumeric designation on engines that certifies the emission level of a particular engine and indicates that the engine falls into a certain "engine family", or grouping of standard engine configurations. It is also sometimes referred to as the EPA Engine Family Name, and can be listed on engine nameplates under "Engine Family" or simply "Family". A vehicle's EFN can be found on either the Vehicle Emissions Control Information Label under the hood, or on the engine nameplate itself. Examples of common formats of EFNs include the following: A) 1997 International Engine with 7.3 liter displacement: VNV7.3C8DAAW; B) 2002 Cummins Engine with 5.9 liter displacement: 2CEXH0359BAB; and C) 2007 Caterpillar Engine with 12.5 liter displacement: 7CPXL12.5ESK. Off road engines have only been certified since 1996, so most engines prior to this model year will not have an EFN. The first character in an EFN for 1996 to 2000 model year engines will be: T for 1996, V for 1997, W for 1998, X for 1999, and Z for 2000. From 2001 to 2009, the first character in an EFN will be the last number in the model year of the engine (1-9). From 2010 forward, the engine model year reverted back to being represented by characters: A for 2010, B for 2011, etc., skipping the letters I, O, Q, U, and Z. Instructions on interpreting EFNs in more depth can be obtained through the specific engine manufacturer. On their website, CARB allows searches of their Retrofit Device Verification Database by entering a vehicle's Engine Family Number <http://www.arb.ca.gov/diesel/verdev/vdb/vdb.php>. This search will return a list of all CARB verified retrofit devices that are verified for and applicable to that EFN and engine. This is an excellent way to get an idea of what technologies are available for each engine in question. The engine horsepower will also be indicated on the engine nameplate. This along with the type and model of the vehicle (Caterpillar 345C excavator, John Deere 710G backhoe, Caterpillar D4H Series II bulldozer, etc.) will be helpful in sizing the retrofit and determining the configuration and layout of the retrofit on the vehicle itself if it is not a direct replacement device. In most cases, the retrofit manufacturer will still have to physically inspect each piece of equipment and take measurements, but this information is a good starting point and can be useful if other vehicles of the same or similar year and model have been retrofitted in the past.

The remaining information to be gathered is more difficult to obtain, but no less important in determining which retrofit(s) are applicable, and the most appropriate to install. On any vehicle that is to have one of the emission reduction technologies discussed in this section installed (with the exception of CCVs), a duty cycle temperature analysis must be performed. Even though nearly every vehicle should easily meet the temperature requirements for DOCs and even FTFs, the heavily variant operating nature of construction equipment means that it is important to still conduct duty cycle testing in order to avoid failure of either the retrofit device or the equipment on which it is being installed. For DPFs, a duty cycle analysis is absolutely necessary to determine whether or not it is possible to equip the vehicle with a passive DPF or if a more expensive active DPF is needed. Many retrofit manufacturers will not honor their advertised reduction percentages, warranties, or even sometimes sell their products without first having duty cycle analysis performed. Details on the process of duty cycle testing and analysis are included in Chapter 4: Methods and Procedures, within the section entitled "Pre-Retrofit Data Logging".

Another important factor that is helpful during the selection of retrofits is the cleanliness of the vehicle's exhaust prior to the retrofit. Age of the engine is a good frame of reference, but especially with older vehicles many variables exist that can cause great variance, such as good or poor maintenance habits over the life of the vehicle. The emission level can be determined in several ways, but one of the more commonly used methods in retrofit applications is opacity testing, which detects the opacity (the degree to which light is prohibited from traveling through a medium) of the exhaust stream. This offers a quick, simple, consistent, and relatively inexpensive method of quantifying the cleanliness of the exhaust for the purpose of determining the various pollution levels of vehicles within a fleet. Combining this information with vehicle usage data such as fuel consumption can give a good indication of which vehicles are producing the highest overall quantity of pollution and be given priority to receive the most efficient retrofits.

In addition to considering all of the above factors and weighting them accordingly when selecting retrofits, any applicable policy, legislation, or contractual requirements that exist must take priority and be adhered to. These mandates must be followed first and foremost, but they are usually flexible enough so that most or all of the above decisions are still relevant as long as the end result is still achieved. Sometimes however, these mandates might specify an alternate method of determining the most appropriate retrofit to install or prioritizing a fleet for retrofit installations. Whether dictated by a mandate or simply available funds, budget will almost always be the ultimate limiting factor. A limited budget is almost always the reason behind the need to prioritize a fleet for retrofits and select the most appropriate retrofit layout, rather than just installing active DPFs on every piece of equipment. Selecting the best configuration of retrofit devices for a fleet of various vehicles based on a limited budget will have a wide variety of possible outcomes, and there is no one standard solution. If requirements state that vehicles must be brought to Tier 4 standards then DPFs should be installed on as many vehicles as the budget allows. If retrofitting the maximum number of vehicles is the goal, then DOCs should be installed across the board, substituting in some FTFs or DPFs to increase emission reduction if all of the vehicles can be retrofitted and there is still a budget surplus. More discussion on these decisions is presented in Chapter 4: Methods and Procedures, within the section "Retrofit Selection, Purchase, and Installation", as well as summarizing the specific relevant experiences of this pilot project in Chapter 6: Conclusion, within the section entitled "Effective Retrofit Selection Process".

Chapter 3: Scope of Work

Project Narrative

The purpose of this project is to capitalize on the experience and funding available at the state and federal levels to accelerate and facilitate reduction of diesel pollution from public works projects managed by the Rhode Island Department of Transportation (RIDOT).

The project must include the following components:

- A review and analysis of available technologies and best practices in use.
- Immediate implementation of a carefully monitored pilot project to reduce diesel emissions from a RIDOT construction project in a highly populated urban area.
- Extrapolation from the pilot project the cost and benefit to RIDOT programs in the state of Rhode Island, along with development of Rhode Island specific contract specifications that meets the legislative act.
- Preparation of a final report summarizing lessons learned, providing a road map for diesel emission reduction on public works projects and identifying the overall effects on the state of Rhode Island.

Specific Project Scope of Work

1. Organize and work with a team to initiate the following tasks.

   a. Finalize the construction project selection.

   b. Establish a regular meeting schedule to track the project progress.

   c. Meet with the Design Engineers to form pilot project bid specification to incorporate the pilot project into the construction bid specification. Prepare contract specifications outlining how the pilot program will be incorporated into the construction project. The specifications will include a detailed time study of the data logging process and a description of what is entailed (non-invasive/non-destructive) duty cycle data analysis. In addition, a schedule will be developed to minimize work disruption: it is anticipated that provisions will need to be made to allow URI access to construction site and equipment on weekends in order to collect and redeploy data loggers.

   d. The review and analysis will include, but not be limited to, an assessment of the relative emission reduction efficiencies, cost and operational issues associated with emission reduction strategies. The focus will be on retrofit technologies but also will consider alternative fuels, fuel-borne catalysts, operational protocols, engine rebuilds, new equipment purchase and anti-idling policies.

e. Develop a matrix of emission reduction strategies approved by the Environmental Protection Agency, (EPA) and the California Air Resources Board (CARB). The matrix will include estimates of the relative emission reduction versus the total cost for each respective strategy.

f. Develop a decision tree for use in selecting retrofit technologies for the pilot program.

g. Work with RIDOT and other stakeholders to apply the decision tree to select appropriate retrofit technology for pilot project.

h. Initiate research, review and report on diesel emission reduction strategies implemented by neighboring states.

i. Determine the overall effects of the legislative act on the state of Rhode Island.

2. Design and implement a carefully monitored pilot program to reduce diesel emissions, specifically PM, from construction equipment utilized on a typical construction project.

   a. Establish an inventory of fleet vehicles of participating general contractor and representative subcontractor(s).

   b. Develop a selection matrix for emission reduction technologies, evaluating cost verses emission reduction efficiency.

   c. Perform pre-operator surveys, data log engine exhaust temperatures to identify duty cycles of all equipment types being utilized on the pilot project and measure opacity of exhaust to determine engine suitability for various retrofit devices and to develop baseline for PM emissions. We are proposing pre- and post-data logging to baseline any change in duty cycle throughout the duration of the contract by change in load on the vehicle performing different tasks in different seasons. Monitoring opacity is a simple way to show reduction in PM.

   d. Facilitate installation of retrofit measures with careful documentation of all costs, time, labor, and materials, associated with the retrofit.

   e. Quantify the total fuel consumption utilized over the duration of the pilot project by vehicle. Qualify that the fuel type being used meets the 2010 EPA standard for Ultra Low Sulfur Diesel ULSD, for Off Road Use.

   f. Calculate the baseline quantity of emissions produced.

3. Develop data into decision tree table and graph format to allow analysis to aid in the determination of the appropriate technology.

   a. Develop decision tree based upon USEPA and CARB criteria

   b. Choose appropriate retrofit technology.

   c. Make recommendations to RIDOT based upon decision tree data analysis.

   d. Provide oversight to retrofit installations.

4. Perform post-retrofit installation Testing.

   a. Perform post-operator surveys, data log engine exhaust temperatures to identify change in duty cycles of all equipment types being utilized on the pilot project and measure opacity of exhaust to determine the percent reduction as a result of the respective retrofit as compared to the baseline pre-retrofit testing.

   b. Quantify the total fuel consumption utilized over the duration of the pilot project by vehicle.

   c. Qualify that the fuel type being used meets the 2010 EPA standard for Ultra Low Sulfur Diesel ULSD, for Off Road Use.

   d. Calculate the quantity of emission reduction over the baseline.

5. Develop a final report based upon the outcome of the pilot project.

   a. Formulate all pilot project data into a report to be provided to URITC, URI CELS, RIDOT, RIDEM and RI General Assembly.

   b. Use the pilot project results to develop "A Road Map for Diesel Emission Reduction in Rhode Island" for off road construction equipment.

   c. Assist RIDOT in developing a RI specific Contract Specification for diesel emission reduction technology programs on RI Public Works Projects.

   d. Assist RIDOT w/ preparation of case study documentation for local, regional and national conferences.

Weekly Tasks

During the construction phase of the contract it is anticipated that a URI Staff member and two Energy Fellow students will be on site a minimum of twice and a maximum of three times weekly. Each weekly visit again is anticipated to last approximately two to four hours. **In any given week no more than ten (10) hours will be spent on site.**

Specific Tasks to be Performed

1. Conduct a brief pre- and post-retrofit interview with the equipment operators and resident engineer to gain a better understanding of the daily use and performance of the equipment that they operate. The operators will be required to answer no more than six questions. This base survey will take no more than 10 minutes per operator.

2. Once per week during routine visits fuel inventory data will be collected. The data needed will include total volume of fuel delivered to the construction site each week and proof in the form of a Bill of Laden that the fuel meets the most recent EPA and

ASTM fuel standard for ULSD for off road and on road construction. The fuel inventory will not require the time of any operators and will be completed within a ten minute time frame.

3. A vehicle inventory will be necessary to track the testing of each vehicle assigned to the project. The vehicle inventory will be required by the general contractor and all subcontractors. An inventory sheet will be provided by URI to be filled out by the general and sub-contractors prior to the commencement of construction. It is anticipated that the inventory list will require periodic updates as each construction phase progresses.

4. Each vehicle assigned to the project by the general contractor and subcontractors and meeting the criteria of the legislature of being on the project for 30 consecutive work days will be pre- and post-retrofit tested for the following.

    a. Opacity Test – to determine the range of carbon and PM (particulate matter) in the exhaust stream.

    b. The Opacity Test is a non-destructive non-installation test that will generally take 15 to 20 minutes per vehicle once the vehicle is warmed up.

    c. The Opacity test must be performed during a normal run time and only once per vehicle pre- and post-retrofit.

    d. Duty Cycle Data Logged – to determine the maximum operating temperature of the exhaust prior to entering the muffler and the percentage of the daily run time that the maximum temperature is maintained.

    e. The Duty Cycle Data Logging – is also a non-destructive test however it does require the initial installation of a temperature probe into the exhaust system prior to the muffler along with the mounting of a data logging device. The installation and launching for the pre-test will take about 30 to 45 minutes and an additional 15 to 20 minutes will be needed to retrieve and down load data.

    f. The post-duty cycle data logging will require less time due to the pre-testing preparation for installation of the data logger and probe. It is anticipated that 15 to 20 minute will be needed for installation and 15 to 20 minutes for retrieval and data down load.

    g. The Duty Cycle Data Logging will also only be required once per vehicle pre- and post-retrofit.

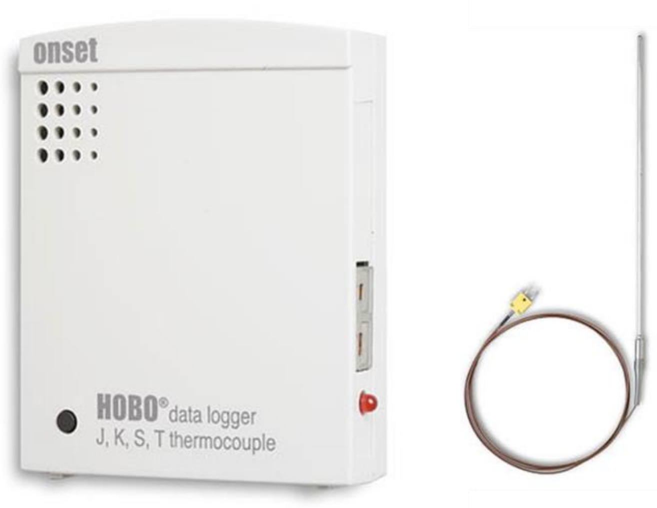
h. It is anticipated that four to six data loggers will be deployed at any one time and deployment will typically be one to two weeks per vehicle. This will be dependent on the overall number of vehicles assigned to the project.

i. **Every effort will be made to avoid disruption of the daily work schedule of the contractor. The installation, launching and retrieving of the duty cycle data loggers can be performed while the vehicle is at idle or during non-construction time. It is anticipated that provisions will need to be made to allow URI access to the construction site and equipment on weekends in order to collect and redeploy data loggers.**

Chapter 4: Methods and Procedures

Equipment

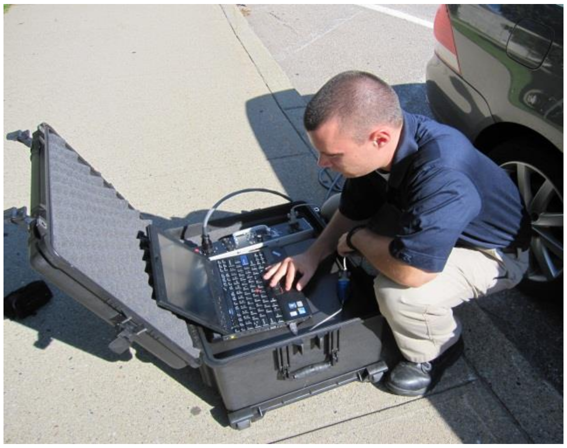
The purchase of several pieces of test equipment was required in order for us to perform the necessary tests to aid in the determination of appropriate retrofit technology. The following is a list of the equipment procured with a brief description of each.



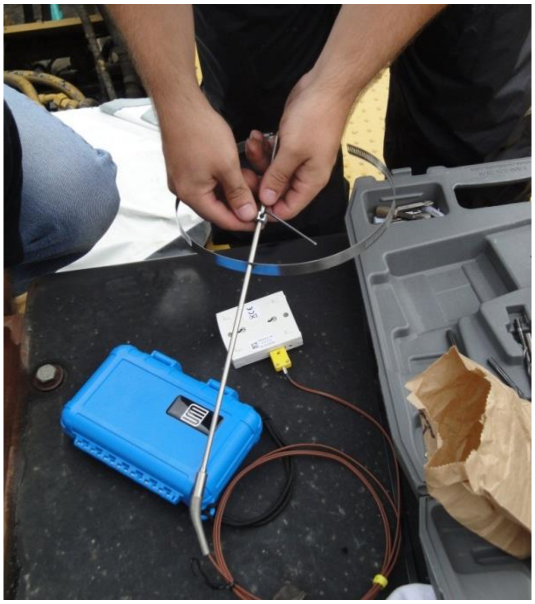
- 6 Onset, HOBO data loggers, Model u12-014, accepting JKS & T thermocouples along with, 6 Thermocouples, (temperature probes),Type K 12 inch Probe Thermocouple Sensor - TCP6-K12. The Data logger and thermocouple pictured as a unit incorporates a micro-processor that logs temperature data signaled from the thermocouple. The data logger can be programmed by the operator for a delayed or immediate launch to gather data at various time intervals via a lap top and provided software. The software allows the data to be formatted into a data table and graphic representation of the data in the table for easy, at-a-glance interpretation. All data is date and time stamped.

- Wager Smoke Meter, Model 7500. This piece of equipment was utilized to analyze the percent opacity of the vehicle exhaust emissions. The unit pictured utilizes a photo sensor to detect and report the percent of light occluded by particles that make up the exhaust stream. There is a very loose correlation between percent opacity and point source pollutants within a vehicle exhaust. In the case of this project percent opacity was utilized to baseline exhaust emissions prior to retrofit and to demonstrate what, if any, reduction was realized post-retrofit.

- Lap Top Computer – Lenovo Model X201, Tablet PC. The laptop pictured was chosen with several criteria in mind. The computer needed to have the ability to handle all of the software, data, photos and documentation gathered throughout the project as with any laptop. This unit also had to able to withstand the harsh environment of a construction site and any weather conditions encountered in the field. The laptop, as mentioned earlier, had to be on onsite because it was the brain behind the data loggers and opacity test equipment.



- Various clamps and protective housings. The clamps and blue protective housings were utilized to attach thermocouples into the exhaust stream, and to protect the data loggers from the harsh construction environment.



Vehicle Inventory List

The pilot project work began with the construction company equipment superintendent compiling a fleet inventory of all equipment to be utilized on the project. An excel spread sheet was provided to the equipment superintendent. This enabled the listing of all pertinent information needed on each piece of equipment to aid in the determination of choosing the correct retrofit technology and to properly format the test equipment for their deployment and the recovery of data.

Even with this equipment list, it was imperative to physically inspect each vehicle listed to manually verify the inventory information. This allowed for the creation of a 100% accurate amended vehicle inventory list.

Applicant Fleet Description Spreadsheet

by Your Agency to Identify the Vehicle	Vehicle License Plate Number	VehicleType (School bus, utility vehicle, dump truck, waste hauler, etc.)	Vehicle Identification Number (VIN)	Vehicle Model Number	Engine Make	Engine Model	Engine Family (listed on engine label)	Engine Serial No.	Engine Model Year	Engine Horsepower	Average Annual Miles	Average Annual Hours	Average Operating RPMs	Muffler Model Number
Example # 999	ABC-123	Refuse Truck	1HTSDAAN6SH635101	321F	International	DT466HT	3NVXH0365F	1823820C1	2003	195	8500	1800		
[redacted]	[redacted]	Gradall Excavator	[redacted]	XL 5100	Cummins	6BTA59-C173 (C8.3-C)	2CEXL0359ABA, 2CEXL0505ABB (on-road)	[redacted]	2002	230		[redacted]	2100	
[redacted]	[redacted]	Backhoe	[redacted]	710G	John Deere	6068TT057	5JDXL06.8041	[redacted]	2005	118		[redacted]	2200	29161A REV E
[redacted]	[redacted]	Track Excavator	[redacted]	345C	Caterpillar	C-13	6CPXL12.5ESK	[redacted]	2006	520		[redacted]	2100	
[redacted]	[redacted]	Articulated Dump Truck	[redacted]	740	Caterpillar	C-15	6CPXL15.2ESK	[redacted]	2006	453		[redacted]	2286	CAT 231-7645
[redacted]	[redacted]	Articulated Dump Truck	[redacted]	740	Caterpillar	C-15	6CPXL15.2ESK	[redacted]	2006	453		[redacted]	2286	CAT 231-7645
[redacted]	[redacted]	Wheel Loader	[redacted]	980F	Caterpillar	3406B	N/A	[redacted]	1992	275		[redacted]	2100	CAT 7N-9674
[redacted]	[redacted]	Wheel Loader	[redacted]	950G	Caterpillar	3126DITA	1CPXL07.2MRB	[redacted]	2001	197		[redacted]	2200	
[redacted]	[redacted]	Wheel Loader	[redacted]	IT62G	Caterpillar	3126DITA		[redacted]	2005	207		[redacted]	1950	CAT 216-1678
[redacted]	[redacted]	Bulldozer	[redacted]	D8R Series II	Caterpillar	3406E	3CPXL14.6ESK	[redacted]	2003	593		[redacted]	2100	
[redacted]	[redacted]	Track Excavator	[redacted]	345C	Caterpillar	C-13	7CPXL12.5ESK	[redacted]	2007	520		[redacted]	1800	
[redacted]	[redacted]	Vibratory Compactor	[redacted]	CS533E	Caterpillar	3054C (2176/2200)	6PKXL04.4RJ1	[redacted]	2006	130		[redacted]	2200	
[redacted]	[redacted]	Bulldozer	[redacted]	D5N	Caterpillar	3126	5CPXL07.2HSK	[redacted]	2005	130		[redacted]	2000	
[redacted]	[redacted]	Bulldozer	[redacted]	D4H Series II	Caterpillar	3204DI	N/A	[redacted]	1990	105		[redacted]	2000	CAT 112-1665
[redacted]	[redacted]	Telehandler	[redacted]	TH103	Caterpillar	3054	2PKXL03.9AK1	[redacted]	2002	105		[redacted]		197-9717

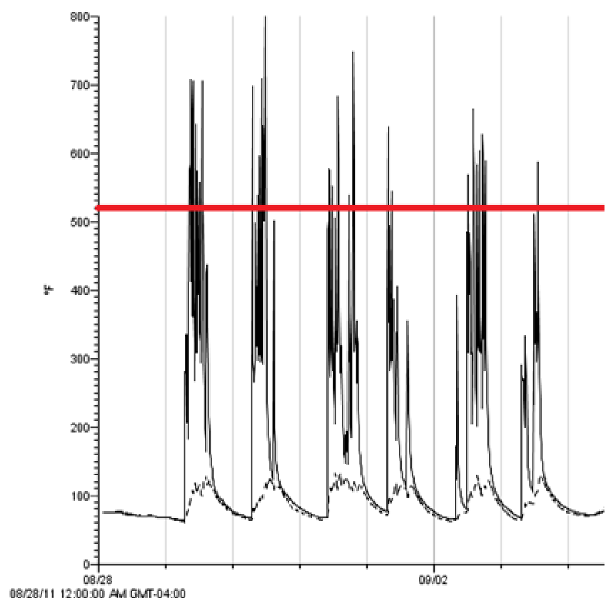
All of the identifying vehicle information has been censored to maintain confidentiality on behalf of the participating General Contractor.

Pre-Retrofit Data Logging

The Onset HOBO Data loggers were utilized to monitor exhaust gas temperature to determine the temperature profile. The testing was performed prior to the existing muffler to determine percent duration and temperature of the duty cycle. A 10 minute time interval was utilized for all temperature data logging tests. Percent duty cycle is expressed as the percent of time that the exhaust temperature immediately prior to the inlet of the muffler reaches a certain temperature. The specific temperature and required percent of duty cycle is specified by the retrofit manufacturer.

The data loggers were deployed on average for a four week period. The data loggers were typically installed and deployed on a weekend during construction down time and programmed for a delayed start of 5:00 AM Monday morning. At any one time at least four data loggers were deployed. The data loggers in this application allowed 24/7 monitoring for a four-week period, capturing the warm-up cycle, operating cycle, cool-down cycle and ambient air temperature of each vehicle. The data loggers were then retrieved and data was down loaded and formulated into a histogram.

The analysis of the histogram data is imperative to for decisions regarding which type of retrofit technology is most appropriate for each piece of equipment. This is a specific requirement in the case of Diesel Particulate Filters, DPF's. All retrofit technologies require a specific Duty Cycle to operate efficiently, however DPF technology requires a much higher temperature for a specified duration to maintain optimal efficiency.



The red line shown on the histogram above was added manually and is meant to give a quick visual representation of the percent of the total duty cycle for which the exhaust temperature of this vehicle exceeded 270° C.

Pre-Retrofit Opacity Testing and Operator Survey

The engine exhaust opacity test procedure consisted of deployment of the Wager Smoke Meter Model 7500 along with the laptop to launch and log the opacity test data.

The test commenced with warming up the vehicle to be tested to operating temperature if the equipment was not actively working. This was done during the set up and installation of opacity test equipment. In most cases the equipment was actively working and opacity testing was performed in the early morning as construction commenced, during a break in construction for that specific piece of equipment, or at the end of the day at shut down.

The testing began by performing a pre-test control reading (to assess the ambient air quality), then insertion of the opacity test probe into the vehicle's exhaust outlet. The unit will start with a countdown of three pre-snap test readings then perform a similar countdown for the three snap acceleration tests. After performing the test the technician must then perform a post-test control reading to compare to the pre-test control reading in what is known as a zero drift test.

The opacity test is then either passed or failed based on the engine model year and the opacity observed, but this pass/fail is an on road diesel vehicle standard that does not apply to off road construction vehicles and has no impact on this project. The pass/fail criteria are pre-programmed into the opacity meter software, regardless of what equipment is being tested. All test data is then date and time stamped and stored in the computer for further analysis.

At the time of each opacity test, a pre-retrofit survey was conducted with each equipment operator. A series of questions was asked of the operator regarding performance, maintenance and operating capacities the equipment being tested. This survey was conducted to serve as a baseline and to be compared to a similar post-retrofit survey with the intent of comparing the two surveys to determine if the equipment suffered any reduction in performance. A copy of the operator survey questions has been provided.

Name: ______________________ Date: ______________ Vehicle ID: ______________________

	Worst		Average		Best	
	1	2	3	4	5	Additional Comments
1) Power: ability to accelerate/operate equipment safely and effectively						
2) Performance: overall reliability and consistency of equipment						
3) Noise: in-cab engine noise levels						
4) Ventilation: in-cab air quality and overall breathability						
5) Environment: outdoor air quality and breathability near equipment						
6) Visibility: ability to view work space and surroundings (line of sight, blind spots, rear view,						
7) Maintenance: ease of equipment maintenence						
8) What is the frequency of engine PM (oil, oil filter, fuel filter, and air filter changes)?						
9) How many operating hours are on this piece of equipment?						
10) How many hours per day (on average) does this piece of eqiupment idle?						
11) What is the OEM recommended operating RPM for this piece of equipment?						
12) How many hours per day (on average) does this piece of equipment operate at the recommended						
13) What is the average daily and weekly fuel consumption of this piece of equipment?	Daily:			Weekly:		
14) Overall equipment rating						

Additional Comments: ____

____

____

____

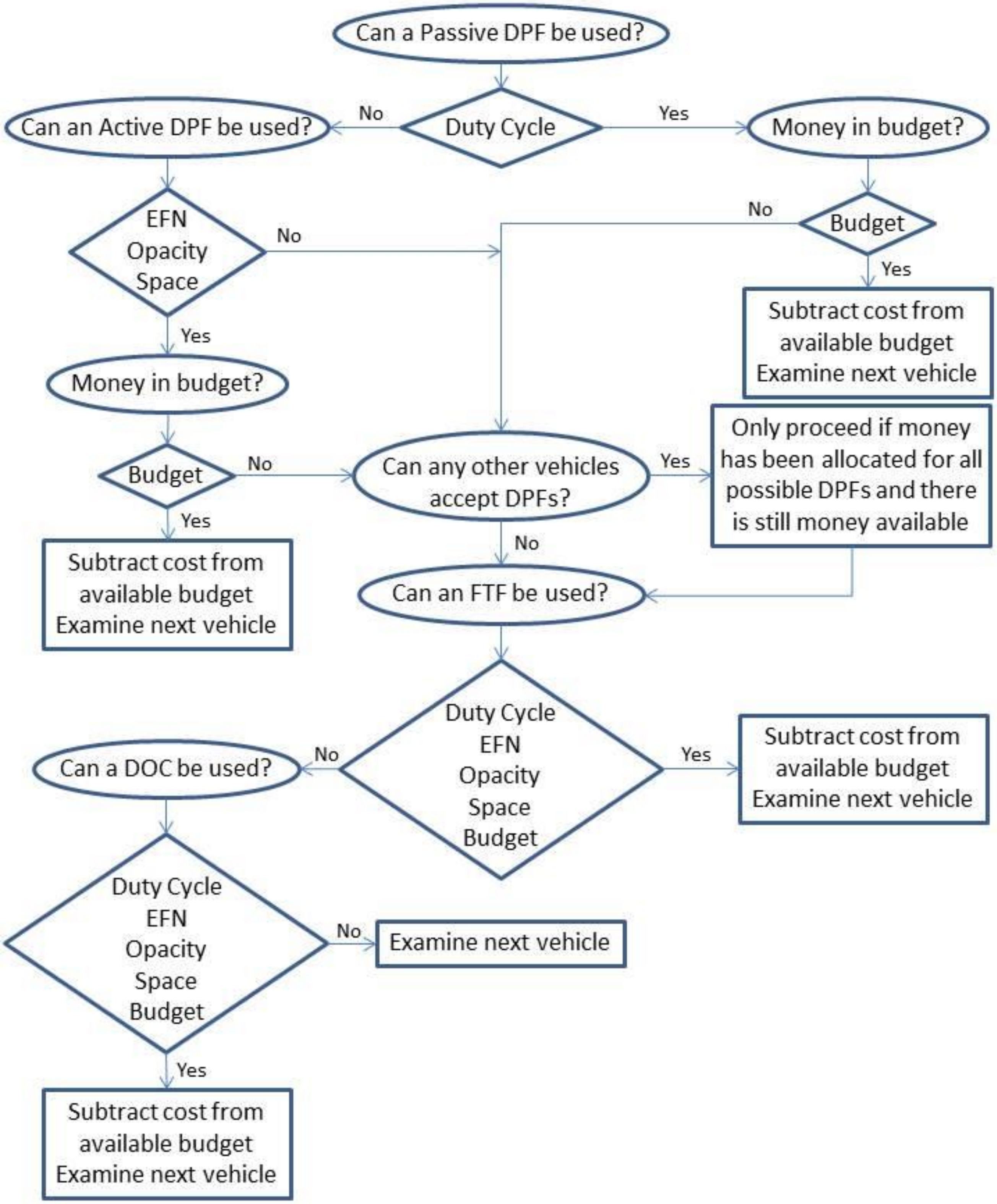
Operator's Signature: ______________________

Retrofit Selection, Purchase, and Installation

This section will discuss the process of selecting the appropriate retrofits based on the specific requirements and goals of a project, providing details regarding the analysis of the various factors that should be taken into account throughout the decision making process. How to prioritize the vehicles in a fleet will be outlined, as well as the procedure for purchasing and finally installing retrofits once they have been selected. Our experiences in each of these areas throughout this pilot project will be shared to provide specific examples.

A good first step in any retrofit selection process is to create a custom decision tree that will act as a set of guidelines for selecting the best retrofit layout for each unique emission reduction situation. This decision tree should be a kind of flow chart that uses the information gathered during the decision making process in conjunction with the desired outcomes of the emission reduction program to point buyers in the best direction to achieve their goals. The data acquired (as detailed earlier in this chapter) in the pre-retrofit phase will be used to select certain "branches" leading down the tree that will ultimately form a path to the most preferential, while still feasible, retrofit solution. Since the data from every vehicle will be different, this decision tree should be applied to each vehicle that is to be retrofitted, in order of highest to lowest priority for receiving retrofits. Prioritizing vehicles is discussed later in this section. A sample decision tree is shown on the following page that assumes goals for the project exist such that: all vehicles should be brought to Tier 4 compliance when possible (meaning the installation of a Level 3 device); when this is not feasible, the Best Available Technology should instead be installed as an alternative (falling back onto Level 2, and then Level 1 devices); if all vehicles that can accept DPFs cannot have DPFs installed due to budget limitations, install as many DPFs as possible in order of highest-to-lowest vehicle priority, only installing Level 1 or 2 devices when all possible DPFs have been installed and money remains in the budget.

Goals: Bring all vehicles to Tier 4 compliance when possible (DPFs); When not possible, use Best Available Technology; For any budget limitations, DPFs get first priority for installation.



The decision tree pictured on the previous page is an example of what a decision tree might look like for the hypothetical goals listed. Since the goals of different projects, contracts, or mandates will differ, a unique decision tree will have to be created whenever the objectives change and customized to that exact set of goals. However, the goals listed should mostly be in line with a majority of legislative and contractual requirements, making this decision tree a good example of a typical retrofit process. Our own decision tree for this project was heavily influenced by the overall goal of this pilot project, which was to examine and compare the various available retrofit technologies in order to determine their efficiency, cost effectiveness, and feasibility. This led us to select different reduction level technologies (not always the most efficient that a particular vehicle could handle) to be installed on similar pieces of equipment for comparison between the different retrofit technologies. Overall reduction was also a goal, but it took a backseat to the investigative research aspect of the pilot project.

Some of the easiest information to obtain about a vehicle can also be some of the most helpful during the retrofit selection process. Having knowledge of the EFN, the model year and horsepower of the engine, and the type of vehicle to be retrofitted can answer important questions that may point toward or exclude certain retrofit options. The EFN is an excellent tool to see what retrofits are available for a certain vehicle, as well as providing the model year of the engine with the first character. Looking at the age of the engine will help the decision making process in several ways: it can help indicate if the vehicle might simply be too old to retrofit, it can influence the decision not to retrofit the vehicle if it is so old that it will soon be retired and is not worth retrofitting, and it can give an idea of the current emission level of the equipment. Age as a means of prioritizing the equipment will be discussed in more detail later on in this section. When using age to determine cleanliness of a vehicle's exhaust, the best place to start is by seeing which emissions Tier (pre-defined levels of emission cleanliness set forth by the EPA) that engine falls under, giving a baseline maximum emissions level at the time of production. Tier 1 standards were phased in from 1996-2000, Tier 2 and 3 from 2000-2008 (although Tier 3 standards for PM were never adopted), and Tier 4 is being phased in from 2008-2015. This information can provide a decent estimate, but as equipment ages the emissions level for those vehicles could remain relatively constant or increase rather dramatically, depending on the maintenance of each vehicle along with other factors. The type of the vehicle (excavator, vibratory compactor, grader) has obvious implications for the available space, configuration, and placement of any retrofits that are not direct replacement. This must be kept in mind when installing non-direct replacement DOCs or FTFs and especially when considering a DPF. Having the exact model of the vehicle can also be very useful for research into whether or not any retrofits (especially comparable retrofits) have been installed on similar equipment, if not on that exact year and model. Retrofit manufacturers can also use this information to more quickly and accurately size retrofit devices. Since every vehicle assigned to this project was opacity tested prior to selecting retrofits and we were not dealing with any excessively old equipment, age became less of a decision factor. We did find that according to our opacity testing, engine model year was a fairly reliable indicator of exhaust cleanliness. Having the EFN and horsepower provided the means for the retrofit manufacturers to provide us with a list of their applicable retrofits.

Obtaining the temperature duty cycle of every vehicle to be retrofitted is imperative. Not only is it essential in determining whether or not a passive DPF can be used successfully on a piece of equipment, but FTFs and DOCs also have temperature requirements and many retrofit manufacturers will not sell their devices (or will not honor their performance guarantees and warranties if they do sell the devices) without having a duty cycle analysis done on each vehicle on which a retrofit is to be installed. It is also important in order to protect the engines themselves. If a passive DPF is installed on a machine that does not adequately meet the duty cycle requirements, that DPF will likely plug and increase downtime of the vehicle while the filter is removed frequently for cleaning. If this happens and the warnings are ignored and the filter is not cleaned frequently, the increased backpressure could damage the engine. If a DOC or FTF is installed on a machine that does not adequately meet the duty cycle requirements, they will not meet their advertised emission reduction percentages. A duty cycle should be obtained and analyzed for every vehicle prior to retrofit purchasing decisions being made. Our duty cycle data allowed us to determine which vehicles were eligible to have a passive DPF installed, and let us know that all of the vehicles were eligible to have either an FTF or DOC installed.

While looking at the engine model year is a rudimentary way to gauge exhaust cleanliness, opacity testing each vehicle will give a more accurate assessment of the level of pollution in the exhaust despite having only a loose correlation to PM content in exhaust. An opacity value allows for the cleanliness of each vehicle to be more closely examined and compared, both to each other and to the average engine of that age. This becomes very useful when prioritizing the fleet to help determine a retrofit layout, and can be a good way to compare pre- and post-retrofit emissions levels to measure achieved reduction. It is important to note that while there is a direct relationship between opacity and PM content in exhaust streams, the correlation is very loose with a large variance. This means that when a reduction in opacity is seen, a reduction in PM is also likely to occur (and vice versa), but there is no guarantee that this will be the case and the amount each decreases could be very different. Due to this loose correlation, a 20% reduction in opacity does not necessarily indicate a 20% reduction in PM. As an example, a 20% reduction in opacity could hypothetically be accompanied by a 50% reduction in PM, a 20% reduction in PM, a 0% reduction in PM, or even a net increase in PM (though this is unlikely), depending on a large number of variables. The correlation between the two will only become looser for smaller diameter particulate matter. For these reasons, opacity tests should not be used as a basis for PM regulation enforcement. Instead, due to the relationship that does exist between opacity and PM, opacity tests are a convenient in-field method of identifying potential high-emitters of PM for the purpose of prioritizing vehicles to receive retrofits. We performed opacity tests on all of the vehicles that were assigned to the project, and this gave us an excellent look at which vehicles had the dirtiest exhaust. This information was vital when we determined the priority of the vehicles to be retrofitted. It was also used to observe any reductions in opacity that had occurred after the installation of the retrofits, which was indicative of a reduction in PM.

A major consideration during the selection of retrofit devices is the requirements set forth by the governing body of the retrofit program. This could be legislative or contractual requirements, or just the objectives of whoever created or is administering the project. Regardless, when these requirements exist they must be followed and thus will shape the retrofit selection process. In fact, they will often form the backbone of the decision tree and provide a detailed guide for selecting retrofits for each eligible vehicle. They will often be similar to the Best Available Technology requirement, which states that a DPF should be considered for every vehicle and only when determined to be not feasible for that vehicle will a less efficient retrofit technology be considered. This process continues down the ladder of decreasingly efficient emission reduction technologies until one is found that can be successfully installed on the vehicle in question. The process then begins at DPF again for each vehicle to be retrofitted. When a program is being executed voluntarily or without any specific goals other than the overall reduction of harmful emissions, or without any requirements detailing how retrofits are to be selected, it is up to the administrators of that program to determine where their priorities lie. Only after detailing more specific goals can an effective retrofit layout be compiled. These goals could be as simple as "install FTFs on every vehicle in the fleet", or be more complicated such as a Best Available Technology strategy. Being a pilot project, this emission reduction program came with a rather unique set of objectives. The overall goal in this case was knowledge and experience, meaning that total emission reduction was still important but was secondary to learning more about the retrofit process. Other than gaining knowledge, there were few strict requirements for selecting retrofits (retrofit all vehicles >50 HP that were on the job site for >30 days), leaving us the freedom to customize the retrofit layout so as to best gain insight into the inner workings of the retrofit process and various retrofit technologies.

During any emission reduction endeavor for which a finite budget limitation exists (nearly always), prioritizing the fleet of vehicles to be retrofitted is a necessary step. Based on the contract specifications or other requirements, certain characteristics might be given more weight when prioritizing vehicles in the fleet. However, in the absence of (or in addition to) these, the three primary factors used are: the pollution level of a vehicle, the age and condition of a vehicle, and the age and condition of a vehicle's muffler. Determining the pollution level is a combination of cleanliness of that vehicle's exhaust combined with how much fuel is burned by that vehicle. This will provide the overall mass quantity of pollution emitted by each vehicle in a metric that allows for direct comparison between vehicles. This was our solution to the problem of determining which vehicles on our project produced the highest overall quantity of pollution, since we wanted to achieve the maximum emission reduction that we could while still fulfilling our goal of becoming familiar with the various retrofits and the retrofit process. We quickly realized that the vehicle with the highest opacity value might not necessarily be the greatest polluter if another vehicle with lower opacity burns a considerable amount more fuel. For example, a vehicle with 10% opacity that burns 1,000 gallons of fuel over the life of a project will likely produce more mass pollutants than a vehicle with 50% opacity that burns only 100 gallons of fuel over the same period of time. To compensate for this factor, we were provided the fueling logs and kept a fuel inventory of the vehicle assigned to this project for the construction season prior to retrofitting. Once we totaled the fuel consumption of each vehicle, we simply multiplied this number (in gallons) by the opacity value that we had previously obtained for each vehicle. This provided us with a weighted pollution index for each of the vehicles that was then used to give us a good idea of which equipment had produced the greatest amount of pollution during that first construction season. We then prioritized the equipment accordingly, ordering our equipment list from highest to lowest overall polluters and considering the highest polluters first for the most efficient retrofits. The other considerations to take into account are the age and condition of the vehicle, engine, and muffler. Even the cheapest retrofits are still relatively expensive, so making sure they go on a vehicle that will be able to fully utilize them is important. Putting a retrofit on a piece of equipment that will likely be decommissioned within the next couple of years might not make much sense monetarily. Also, as outlined in the requirements of the emission reduction technology, the engine must be in good working order and not consuming excessive amounts of lube oil. Putting any retrofit on an engine that is in poor working order is a recipe for disaster. We did not run into these issues during our project, for two reasons. The first reason is that contractual specifications stated that every vehicle that was on the job site for at least 30 consecutive construction days and had a 50 HP or greater engine had to receive a retrofit of some kind. Secondly, none of the vehicles or their respective engines that met these eligibility qualifications were in poor enough condition to warrant any concerns. As for the condition of the muffler, this is important to consider because it will almost always be replaced by whichever retrofit device is installed. While mufflers are not nearly as expensive as retrofit devices, it is still a cost that can possibly be avoided by giving a vehicle with a failing or failed muffler priority to be retrofitted. Purchasing and installing a replacement muffler and then replacing that new muffler a few months later when retrofitting that vehicle is a potential waste of money. This is not a major consideration when prioritizing a fleet, but it should still be kept in mind. We did not encounter this as a factor during this project.

Budget constraints will often be the largest limitation on the process of selecting retrofits for a fleet of vehicles. Even if emission reduction is the highest priority and every single vehicle can accept a passive or active DPF without issue, a finite budget will likely be consumed quickly by these costly retrofits. Depending on the circumstances of the retrofit program, various levels of funding may be provided to pay for the retrofits and their installation costs. In the case of the Rhode Island's Diesel Emission Reduction Act, "Emission controls shall be required only to the extent of available reimbursement from project funds covering the equipment purchase and installation labor costs of the controls, provided that at least one percent (1%) of the total of each project budget shall be dedicated for such reimbursement". This applies to any public works contract or contracts where the state is funded in whole or in part by federal monies and where the total project cost is at least five million dollars ($5,000,000). Assuming 1% of a $6,000,000 budget is allocated to cover the equipment purchase and installation labor cost of emission controls, this would provide $60,000 for that purpose. Further assuming that DPFs for the project cost $15,000 each, on average, 4 vehicles could then be retrofitted. This is not taking into account the costs associated with the testing necessary to determine the applicability of the DPFs, the cost of equipment downtime and/or transportation to a retrofit installation facility, or the cost of the time and efforts of the individual who is in charge of overseeing the retrofitting process. If there are 8 vehicles eligible for retrofit on that project, decisions must be made as to which 4 will receive the DPFs, or possibly to install a greater number of less expensive but less efficient retrofits. It is easy to see how budgets can pose significant limitations on the retrofit selection process and why prioritizing a fleet is necessary. Due in large part to this being a pilot project, we were allocated a force account of 3.1% of the total construction project budget to cover the equipment purchase and installation labor cost, since the actual costs incurred on a project such as this one were largely unknown. There were 14 vehicles on this project that were eligible, and therefore required, to receive retrofits. One of the vehicles (the Gradall Excavator) had two engines, so in total 15 engines were retrofitted. The layout of these retrofits is: 1 active DPF, 1 passive DPF, 7 FTFs, and 6 DOCs. All of these retrofits were installed using less than 2.2% of the total construction budget, or only about 70% of our originally allocated retrofit budget. This 2.2% included the cost of the retrofit equipment purchase, installation labor costs, as well as downtime and transportation costs for the three vehicles that had to have their installations done at an offsite location due to complexity. However, this does not include the cost of the time spent testing equipment for retrofit applicability, prioritizing the fleet, selecting the retrofits, and overseeing the retrofit selection and installation process. It is also important to note that some less efficient retrofit technologies were selected for educational purposes. Even considering all of the above factors, our expenditures ended up being 2.5 times the 1% minimum stated in Rhode Island legislation. Needless to say, we would not have been able to retrofit nearly as many vehicles if only provided the minimum budget. This would have led to a much more difficult decision making process when choosing which vehicles to retrofit with which devices, further stressing the importance of always prioritizing the fleet of vehicles to be retrofitted.

With proper planning and adequate knowledge of the desired goals and outcomes of a project, finalizing retrofit selections should not be difficult. Making the final layout decisions will simply be a culmination of all of the smaller decisions listed above based on the acquired data and stated program objectives. Putting all of this together will point towards the proper path for the project's retrofit purchases. If the decision tree that was created for the project is followed, and used in conjunction with the priority of each vehicle, there should be few issues with selecting the appropriate devices.

The retrofit technology purchase and installation bid process went as follows. Due to the Waterfront Drive construction project having been awarded to a specific construction company and the force account allocated in advance to pay for the retrofit technology purchase and installation being a part of this contract award, the construction company had full responsibility for bidding and award of the retrofits. Specific direction was given to the construction contractor in drafting the bid specification to insure that the specification met the needs of project. This included but was not limited to technology choice, data acquisition and budget constraints. It is recommended for all projects that a not-to-exceed budget figure be calculated for the retrofit portion of the project. A sample bid specification draft similar to the one used for the purchase and installation of retrofits for this pilot project is included on the following pages. Note that all identifying information has been removed. The last page of this specification is a Cost Sheet Attachment that was provided to the bidders as an easy way to disseminate all pertinent vehicle information while simultaneously allowing a location for bids to be written in upon bidder response.

Job Specific
xxxx-xxxx
Date
xxxxx-xx-xxx
Page x of x

ITEM CODE 12.100.9901
Diesel Emissions Reduction Program

Description:
All diesel on-road and non-road powered construction equipment with horsepower (HP) ratings of 50 HP and above that are on the project or assigned to the contractor for a period in excess of 30 days shall be subject to data logging to determine the most effective emission control device/s to yield the most efficient reduction of diesel emissions. The work under this item consists of the general contractor retaining an emissions technology installer to retrofit certain emissions devices in accordance with the Rhode Island general laws for Diesel Emissions Reduction Act 2010 – S2440.

Applicable Laws and Regulations:
All motor vehicles and construction equipment (both on-road and non-road) shall comply with all applicable Federal, State and local laws and regulations relative to exhaust controls and safety.

Bidder(s) must include at least (1) one product and installation service for any of the 3 levels of control equipment, or (2) at least one product and installation service of a closed crankcase ventilation system. The equipment includes:

- **"Level 1 Control" Diesel Oxidation Catalyst (DOC)** – means a verified diesel emission control device that achieves a particulate matter (PM) emission reduction of twenty percent (20%) or more compared to uncontrolled engine emission levels.
- **"Level 2 Control" Flow-Through-Filter (FTF)** – means a verified diesel emission control device that achieves a particulate matter (PM) emission reduction of fifty percent (50%) or more compared to uncontrolled engine emission levels.
- **"Level 3 Control" Diesel Particulate Filter (DPF)** – means a verified diesel emission control device that achieves a particulate matter (PM) emission reduction of eighty-five percent (85%) or more compared to uncontrolled engine emission levels, or that reduces emissions to less than or equal to one one-hundredth (0.01) grams of (PM) per brake horsepower-hour. Level 3 control includes repowering or replacing.
- **"Closed Crankcase Ventilation" system (CCV)** – means a system that separates oil and other contaminant from the blow-by gases and routes the blow-by gases into a diesel engine's intake system downstream of air filter.

Shop Drawing Submittals:

(1)An inventory list of all General and Subcontractor owned on-road and non-road diesel powered construction equipment with engine horsepower (HP) ratings of 50 HP and above, that will be on the project or assigned to the contract for a period in excess of 30 days and utilized on the project. The inventory list shall include:

1. Contractor name/address/contact person;
2. Equipment type, model, serial number;
3. Engine serial number, make, model, year of manufacture; and
4. Estimated construction activity and anticipated duration to remain on site.

(2) Weekly update logs, which list all of the on-road and non-road diesel equipment details as in above submittal (1), date on site, date off site and fuel usage of all contractor and subcontractor vehicle and equipment with 50 HP and above utilized on the project beyond the 30 day minimum. The weekly log shall be submitted in electronic format and hard copy. Weekly fuel logs shall be submitted to the Resident Engineer with the bar code, equipment make & model, fill date, quantity & quality of fuel.

(3) Submit digital pictures (four minimum) of equipment designated as a candidate for a retrofit device showing vehicle and engine. Also, the past maintenance records shall be submitted for each designated equipment.

Anticipated Program Activities (Mandatory by the Contractor):

General During the construction phase of the contract it is anticipated that member/s of the retrofit contractor will be on site during construction. Each visit is anticipated to last approximately two to four hours. In any given week no more than ten (10) ten hours will be spent on site. The general contractor shall accommodate the installation contractor representative to the best of their ability so as not to cause delays or work stoppage.

Specific Program Tasks to be performed:

1. Conduct a brief pre and post retrofit interview with the equipment operators and Resident engineer to gain a better understanding of the daily use and performance of the equipment that they operate. The operators will be required to answer no more than six questions. It is anticipated that the base survey will take no more than 10 minutes per operator.

2. Once per week during routine visits fuel inventory data will be collected. The data needed will include total volume of fuel delivered to the construction site each week and proof in the form of a Bill of Laden that the fuel meets the most recent EPA and ASTM fuel standard for ULSD for off road and on road construction. The fuel inventory shall not require the time of any operators and anticipated to be completed within a ten minute time frame.

3. A vehicle inventory list will be necessary to track the testing of each vehicle assigned to the project. It is anticipated that the inventory list shall require periodic updates by the Contractor as the construction schedule progresses.

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4. Each piece of construction equipment designated as a candidate for a retrofit shall be pre and post retrofit tested for the following:

A. Opacity Test – to determine the range of carbon and PM in the exhaust stream. The Opacity Test is a non-destructive non-installation test that will generally take 15 to 20 minutes per vehicle once the vehicle is warmed up. The Opacity test must be performed during a normal run time and only once per vehicle pre and post retrofit.

B. Duty Cycle Data Logged – to determine the maximum operating temperature of the exhaust prior to entering the muffler and the percentage of the daily run time that the maximum temperature is maintained. The Duty Cycle Data Logging – is also a non-destructive test however it does require the initial installation of a temperature probe into the exhaust system prior to the muffler along with the mounting of a data logging device. The installation and launching for the pre test will take about 30 to 45 minutes.

C. The post duty cycle data logging will require less time due to the pre testing preparation for installation of the data logger and probe. It is anticipated that 15 to 20 minute will be needed for installation.

Method of Construction:

Pre Retrofit Installation

A. The Contractor shall submit all necessary Shop drawings.

Installation of Retrofit Device

A. The Contractor will obtain an approved installer. The Installer shall retrofit the selected emission device/s to the designated Contractor owned equipment.

B. Acceptable Diesel Retrofit technologies/devices for the Project shall be included on the US Environmental Protection Agency (EPA) or California Air Resources Board (CARB) Verified Retrofit Technology List.

Post Retrofit Installation

A. Diesel emission reduction systems and engines must be operational, maintained and serviced as recommended by the manufacturer.

Method of Measurement:

This item will be calculated for payment by the actual cost, verified by the force account records for installation of the retrofit device and paid invoices by the Contractor. The Contractor shall pay by certified check the installer the installation costs for the emissions retrofit device. The contractor shall be reimbursed by the Resident Engineer upon the installer's receipt of payment.

Basis of Payment:

This item shall be paid for under item code number xxx.xxxx.

The estimated dollar figure for this item of work is established by the Department at xxx units at $1.00 each and is inserted in the proposal as an authorized amount from which payments will be drawn. The price so stated shall constitute full compliance for all labor, materials and all other incidentals required to finish the work, complete and accepted by the Engineer.

There shall be no additional time or payment granted to the contractor for compliance with this specification with the exception of the installers cost, All costs associated with implementation of the diesel equipment emissions control devices, associated contractor downtime, equipment maintenance and training costs shall be borne by the respective contractor and included in their cost for performing the work of the contract. The contractor's compliance with this specification and any associated regulations shall not be grounds for claims.

GENERAL BIDDER INFORMATION AND CHECKLIST

All bidders must fully complete and return this attachment with their response

I. Bidder Information

Bidder/Company Name: ____

Contract Contact: ____

Address: ____

City: _______________________ State: ______________________ Zip: ___________________

Phone: _____________________ Fax: ______________________ Email: ___________________

Account Manager Contact (if different): ____

Phone: _____________________ Fax: ______________________ Email: ___________________

II. Category Response

Bidder is submitting a response for the following categories (please check all that apply):

Level 1 Control –	Diesel Oxidation Catalyst (DOC)	☐ Yes	☐ No
Level 2 Control –	Flow-Through Filter (FTF)	☐ Yes	☐ No
Level 3 Control –	Diesel Particulate Filter (DPF)	☐ Yes	☐ No
Closed Crankcase Ventilation Filter (CCV)		☐ Yes	☐ No

III. Information

Does bidder offer additional (added value) products in the category for which they are responding? ☐ Yes ☐ No

If yes, bidders shall attach a separate sheet to their response that provides a general description of the product as well as an estimated price range.

IV. Installation, Training, and Inspection

Bidder agrees to provide all information and services necessary to ensure proper use of the installed devices. ☐ Yes ☐ No

V. Alternative Specifications

Is bidder proposing alternative minimum specifications from those required in this RFP for any product being offered? ☐ Yes ☐ No

If yes, bidders must attach a separate sheet that identifies the product, actual content and rationale for approval of such alternatives.

VI. Forms and Attachments

Has bidder completed and submitted the appropriate Cost Sheet Attachment(s) for each product category in which the bidder is responding? ☐ Yes ☐ No

Retrofit Model	Retrofit Cost	Install Cost	Unique Vehicle ID	Vehicle Type	Vehicle Identification Number (VIN)	Vehicle Model Number	Engine Make	Engine Model	Engine Family (listed on engine label)	Engine Serial No.	Engine Model Year	Engine Horsepower	Average Operating RPMs	Muffler Model Number
					210017662		Cummins	C8.3-C	3NVXH0365F		2005	230	2100	
					T0710GX954062		John Deere	6068TT057	2CEXL0359ABA, 2CEXL0505ABB (on-road)		2006	118	2200	29161A REV E
					CAT0345CPPJW01221		Caterpillar	C-13	5JDXL06.8041		2006	520	2100	
					B1P01420		Caterpillar	C-15	6CPXL12.5ESK		2006	436	1700	
					CAT00740VB1P01321		Caterpillar	C-15	6CPXL15.2ESK		2006	453	2286	CAT 231-7645
					8CJ00354		Caterpillar	3406B	6CPXL15.2ESK		1992	275	2100	CAT 7N-9674
					5FW02105		Caterpillar	3126DITA	N/A		2001	197	2200	
					CATIT62GEAYA00262		Caterpillar	3126DITA	1CPXL07.2MRB		2005	207	1950	CAT 216-1678
					6Y201524		Caterpillar	3406E			2003	593	2100	
					CAT0345CAPJW01789		Caterpillar	C-13	3CPXL14.6ESK		2007	371	1800	
					CATCS533TASL01591		Caterpillar	3054C	7CPXL12.5ESK		2006	130	2200	
					AKD01773		Caterpillar	3126	6PKXL04.4RJ1		2005	130	2000	
					* 9DB04078 * 8E2045		Caterpillar	3204DI	5CPXL07.2HSK		1990	105	2000	CAT 112-1665
					CATTH103C3PN02768		Caterpillar	3054	N/A		2002	105		197-9717

The State of Rhode Island Department of Environmental Management Air Quality Division had previously issued a Request for Proposals (RFP) to establish a preapproved bid list of qualified diesel emission retrofit installers for a state wide school bus retrofit program. This preapproved bidders list served as the list of qualified installers to which the construction project retrofit bid requests were sent. There was no public advertising required in this circumstance because the overall construction project was advertised with the retrofit portion as part of the Waterfront Drive Construction Project. The bid was sent out to six prequalified installers; three no bids were received and three bid proposals were received. The bid was awarded at the discretion of the construction company with the guidance of The University of Rhode Island project team reviewing all aspects of the bid to assure that the proposed technology met the needs of the pilot project.

The availability of emission control devices will depend greatly on the level of demand around the time they are being purchased. Due to the rarity of the precious metals being used in these devices, there will always be some delay in production and distribution. Many retrofit manufacturers also custom manufacture each and every retrofit device, so this too will add some time between ordering and receipt of the product. The delay on DOCs will usually be the shortest, followed by FTFs and passive DPFs in the middle, while active DPFs will most likely come with the longest delay. Our own experiences were very positive on this project. All of the DOCs and both the passive and active DPFs were received within 2-3 weeks of placing the order, although the heat shield for the active DPF was not received until several weeks later. All of the FTFs were received within 4-6 weeks of placing the order. These time frames were all very consistent with what the vendor originally indicated at the time of purchase. It is wise to allow for at least 4-6 weeks between the time the components are ordered and their receipt. Ultimately, the vendor or manufacturer should be consulted, as they will have a more accurate estimate at the time of purchase.

Once the retrofits begin arriving, the next step is getting them properly installed onto the vehicles. Different manufacturers and vendors will have different policies regarding who is authorized to install their devices, but most often the case will be that an authorized installer will need to be the one performing the installations. This authorized installer is often the vendor through whom the emission reduction technologies are purchased. If the customer is in a situation where they feel capable to perform the installations themselves, the manufacturer might be willing to work with the customer to allow this. However, in most cases the retrofit installations are performed by a third party. The length of every installation will vary, depending greatly on the complexity. The average retrofit installation will take approximately 1-3 hours for a DOC, 2-5 hours for an FTF, 15-30 hours for a passive DPF, and 20-40 hours for an active DPF. All 6 of the DOCs that were installed on this pilot project were direct replacement devices and none of the DOC installations took longer than 1.5 hours from start to finish. Of the 7 FTFs that were installed on this pilot project, 5 were direct replacement devices. All of the FTF installations took between 30 minutes and 5 hours from start to finish depending on complexity. The installation of the passive DPF on the 2007 Caterpillar 345C excavator assigned to this project took 30 hours to complete, while the active DPF installation on the upper structure engine of the 2002 Gradall XL 5100 excavator assigned to this project took 40 hours to complete.

Added complexities in an installation can include difficulty accessing the muffler, or having to design, fabricate, and add components to the equipment. With DOCs, the only factors that usually come into play during installations are: difficulty in accessing and removing the muffler on the machine, any reinforcement to the existing mounting system that may be needed, and any (likely minor) modifications that would need to be made to the equipment in the case of a non-direct replacement device. Every DOC installed on this project was a direct replacement device and all of the mounting systems were in good shape and fully capable of supporting the DOCs; the only installation setbacks experienced with DOCs was the occasional difficulty in accessing and removing the existing muffler.

2006 Caterpillar 345C Excavator

1990 Caterpillar D4H Series II Bulldozer

2001 Caterpillar 950G Wheel Loader

2005 Caterpillar D5N Bulldozer

2002 Caterpillar TH103 Telehandler

2006 Caterpillar 740 Articulated Dump Truck

The same factors apply to FTF installations, although it is more likely to encounter a non-direct replacement FTF than DOC, and more major modifications to the body of the vehicle could be needed since FTFs have the potential of being larger than their DOC counterparts. The 5 direct replacement FTF installations on this project were identical to the DOC installations in that the only issues encountered were some difficulty in accessing and removing some of the existing mufflers.

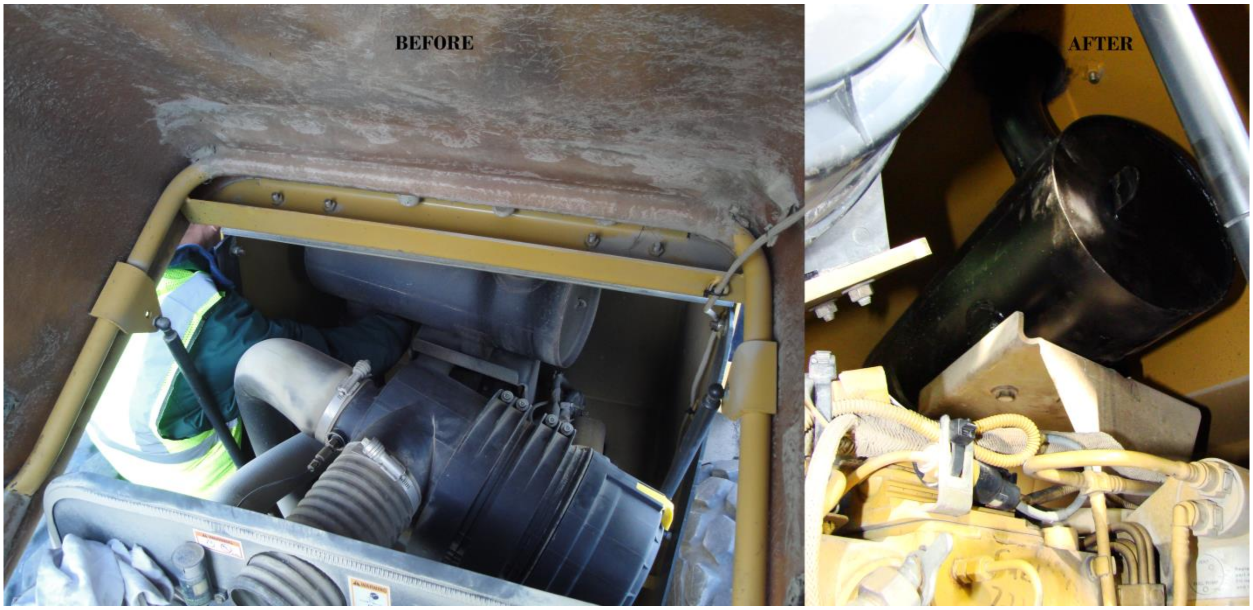
2005 Caterpillar IT62G Wheel Loader

1992 Caterpillar 980F Wheel Loader

2003 Caterpillar D8R Series II Bulldozer

2002 Gradall XL 5100 Excavator

2006 Caterpillar CS533E Vibratory Compactor

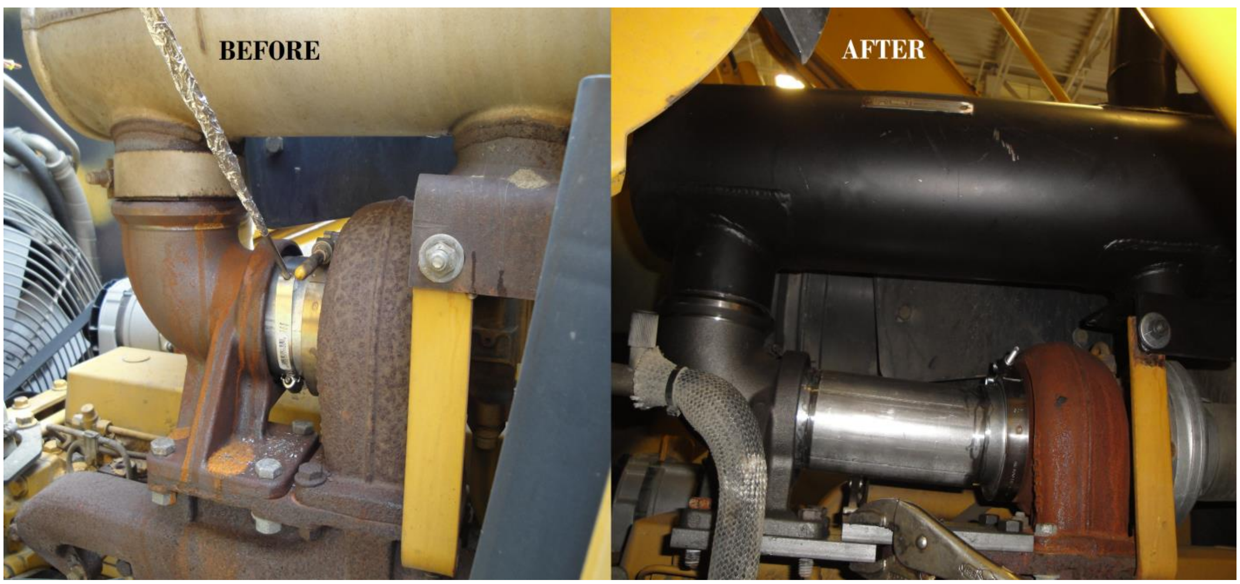


One of the non-direct replacement FTFs was done in the field on a 2006 Caterpillar 740 articulated dump truck and did not take much longer than an hour, despite having to modify the hood of the vehicle and reroute the exhaust piping in order to mount the FTF on the front fender of the vehicle.

2006 Caterpillar 740 Articulated Dump Truck

The other non-direct replacement FTF was installed on a 2005 John Deere 710G backhoe. Because there was a moderate amount of body modification that needed to be performed in order to accommodate the FTF retrofit, this installation was done off-site. The modification involved purchasing a new cast iron elbow from John Deere that was used in conjunction with fabricated piping in order to extend the exhaust line exiting the turbo charger so that it would reach the inlet of the FTF. No modifications are visible from the exterior of the machine; they are all underneath the hood. Including the modifications, the installation took approximately 5 hours to complete. This vehicle was originally selected to receive an active DPF and quoted for one, but it was later determined that it would not be feasible to install such a retrofit device onto this vehicle due to size constraints.

2005 John Deere 710G Backhoe



The lack of direct replacement DPFs means that every one of these installations has an added level of complexity right from the start. These installations require that a location be selected on the vehicle where the DPF can be mounted, the fabrication and installation of adequate mounting hardware, the existing exhaust piping be re-routed, and a backpressure monitor be mounted somewhere in the cab. This is a lot of extra planning and work beyond what is necessary for the installation of DOCs and FTFs, which is why DPFs take so much longer to install. Although not a direct replacement device, the passive DPF that was installed on the 2007 Caterpillar 345C excavator on this project was very close in shape and size to the original muffler

2007 Caterpillar 345C Track Excavator

It was able to be housed inside the same compartment that the original muffler was removed from, but minor modifications to the chassis were still needed. Because of this, the exhaust piping did not need to be re-routed, making this a relatively simple DPF installation. The modification of the chassis and the need to route the wiring for the electrical system, temperature and backpressure sensors along with the computer that controls them, and the backpressure monitor were still a considerable task and took significant time to complete. Overall, this installation took 30 hours.

The active DPF installed on this project was installed on the upper structure engine of a 2002 Gradall XL 5100 excavator. This DPF was unable to fit within the compartment from which the muffler was removed, so was instead mounted directly on top of where the muffler was originally located.

2002 Gradall XL 5100 Excavator

This created a space close to the DPF for the computer and extra fuel lines to be located, and also allowed for only minimal modification of the exhaust piping. Some minor chassis modification was needed in order to get the exhaust piping out of the compartment where the muffler was housed and into the inlet of the DPF. The location of the DPF was almost directly above the engine, which made it easier to tie into a fuel line to supply the afterburner portion of the active DPF. This installation took 40 hours in total.

The cost of any installation is primarily controlled by the amount of labor necessary to complete that installation along with how long it takes. Obviously a more complex and difficult install will take longer and require more labor. The other major contributor to installation cost is the price of parts and labor for any fabrication that must be done as a part of the retrofit installation. These costs can fluctuate significantly, especially if any unforeseen issues arise during installation. If a price ceiling is not agreed upon prior to installation, excess unexpected costs could accrue quickly. Therefore, it is advisable to agree on a “not-to-exceed” installation cost with bids or when purchasing retrofit devices (especially DPFs) as detailed in the bid process section above.

When installations become more complicated, and especially when they require fabrication and equipment modification, the likelihood that they can be successfully completed in the field decreases greatly. Simple direct replacement installations for DOCs and FTFs should almost always be feasible on-site, and so too will even some of the more straightforward non-direct replacement DOC and FTF installations. For instance, all of the direct replacement DOC and FTF installations on this project were performed on-site with no issues. One of the two non-direct replacement FTF installations was done on-site successfully, while the other was a bit more involved and needed to be done at the vendor’s facility. Both of the DPF installations required the vehicles to be transported to the vendor's facility, as is almost always recommended for DPF installations. Of course, the transportation of a vehicle off-site will incur additional costs in the form of transportation and downtime. These costs could potentially be classified as installation costs, depending on the prerogative of whoever is overseeing the project or providing the funding for the retrofits. Regardless, they are not negligible and should not be forgotten.

Post-Retrofit Data Logging

The pilot project relied upon built in monitoring devices installed as part of the retrofit technology to verify no change in temperature profile or duty cycle. For the purpose of this pilot project the pre-retrofit temperature data logging was compared to the monitoring device temperature and back pressure data to assure that as per the retrofit manufacturer the duty cycle remained unchanged.

Post-Retrofit Opacity Testing and Operator Survey

The post-retrofit opacity testing procedure consisted of a repeat of the same process utilized in the pre-retrofit opacity test. The purpose of the post-testing was to compare the pre- and post-test results in an effort to observe any change in opacity. Although this is a loose comparison a reduction in percent opacity is still almost always indicative of a reduction in PM. Once again the opacity test is then either passed or failed, date and time stamped and the data is stored for further analysis.

A post-retrofit operator survey was planned in order to compare this against the pre-retrofit operator survey that was conducted. With the intent of noting any change in vehicle performance observed by the operator.

This became an issue during the post-opacity testing because in all but one case the equipment operators had changed at some point along the time line of pre- and post-analysis. This resulted in a disruption in our survey protocol rendering our results invalid.

Name: ____________________ Date: ____________ Vehicle ID: ____________________

	Worst		Average		Best	Please rate the retrofitted vehicle compared to the original vehicle			
	1	2	3	4	5	Better	Same	Worse	Additional Comments
1) Power: ability to accelerate/operate equipment safely and effectively									
2) Performance: overall reliability and consistency of equipment									
3) Noise: in-cab engine noise levels									
4) Ventilation: in-cab air quality and overall breathability									
5) Environment: outdoor air quality and breathability near equipment									
6) Visibility: ability to view work space and surroundings (line of sight, blind spots, rear view,									
7) Maintenance: ease of equipment maintenence									
8) What is the frequency of engine PM (oil, oil filter, fuel filter, and air filter changes)?									
9) How many operating hours are on this piece of equipment?									
10) How many hours per day (on average) does this piece of eqiupment idle?									
11) What is the OEM recommended operating RPM for this piece of equipment?									
12) How many hours per day (on average) does this piece of equipment operate at the recommended									
13) What is the average daily and weekly fuel consumption of this piece of equipment?	Daily:			Weekly:					
14) Overall equipment rating									

Additional Comments: ____

____

____

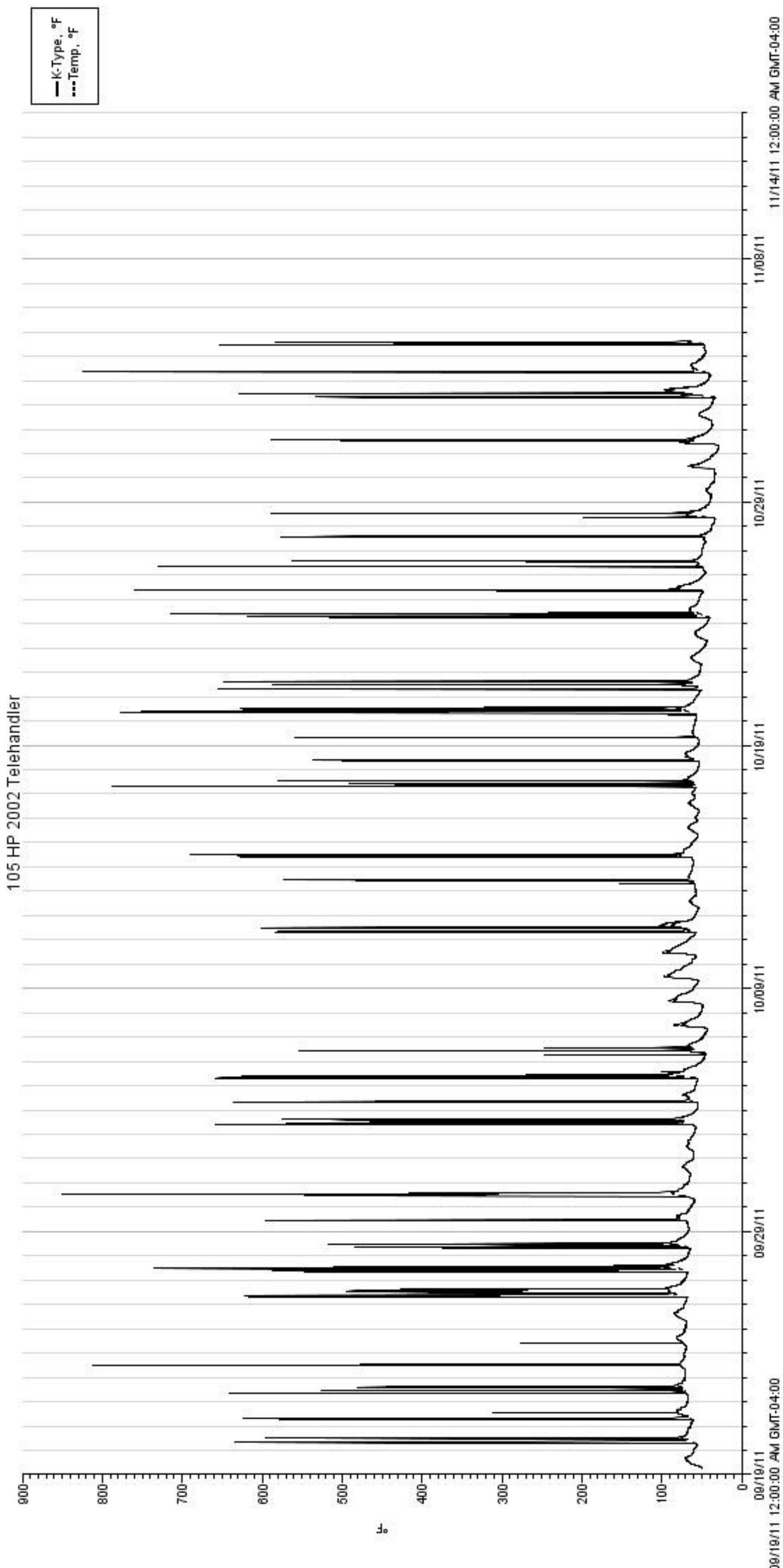
____

Operator's Signature: ____________________________

Chapter 5: Results

Pre-Duty Cycle Analysis

The histograms shown on the following pages are a graphical representation of the data points that were obtained by recording temperature data from each of the vehicles on this project for 3-4 week deployments with 10 minute read intervals.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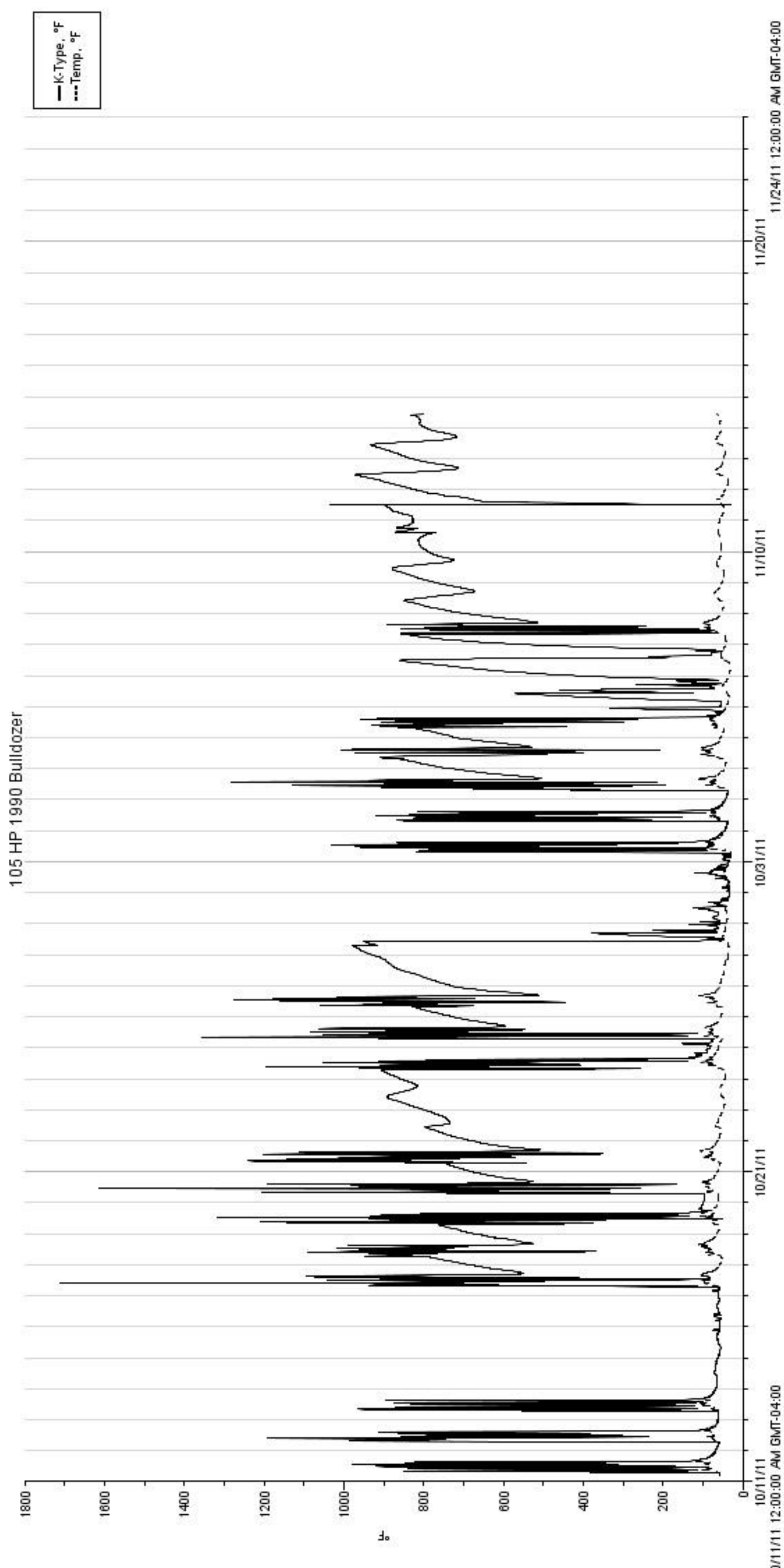
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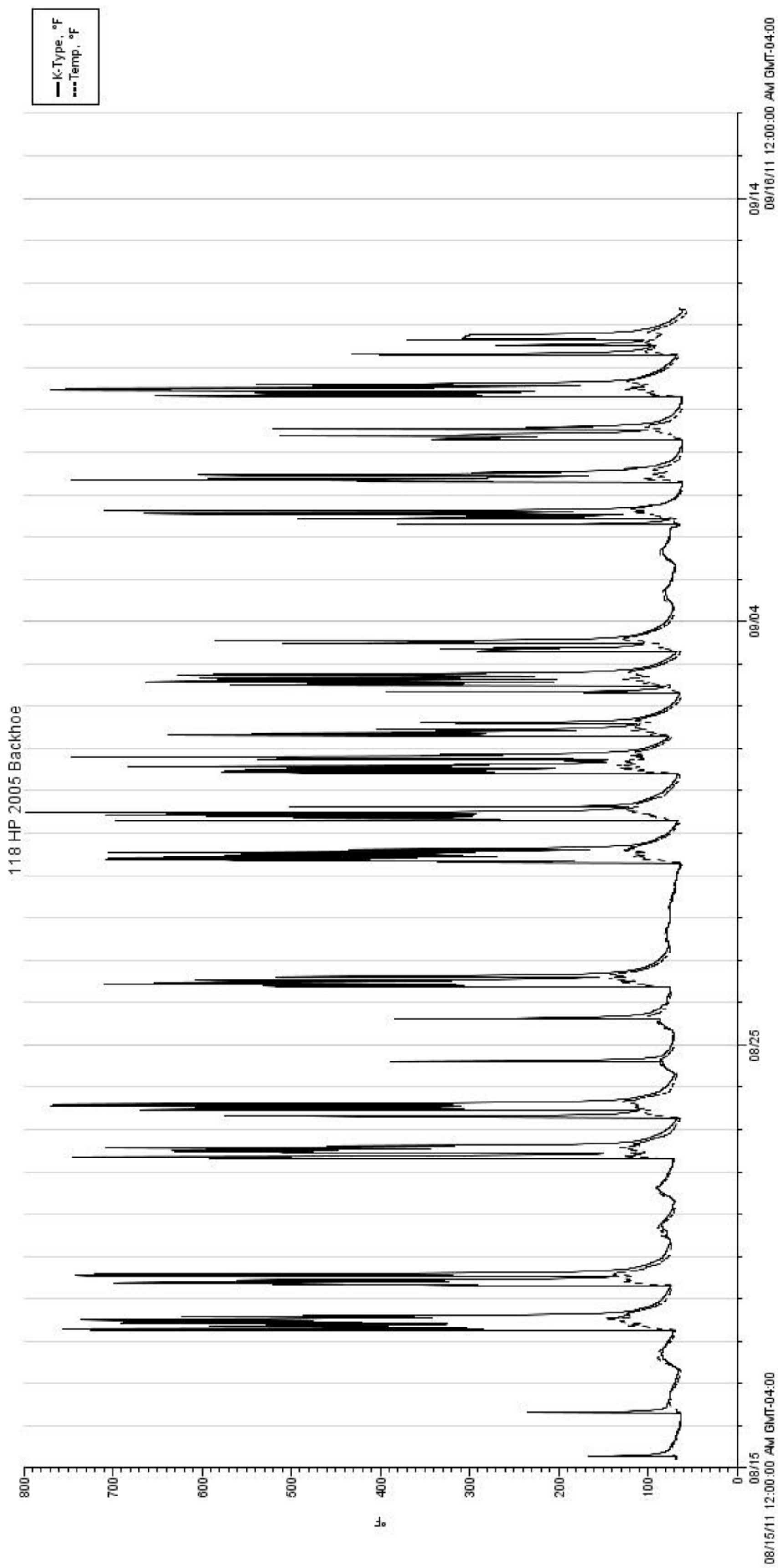
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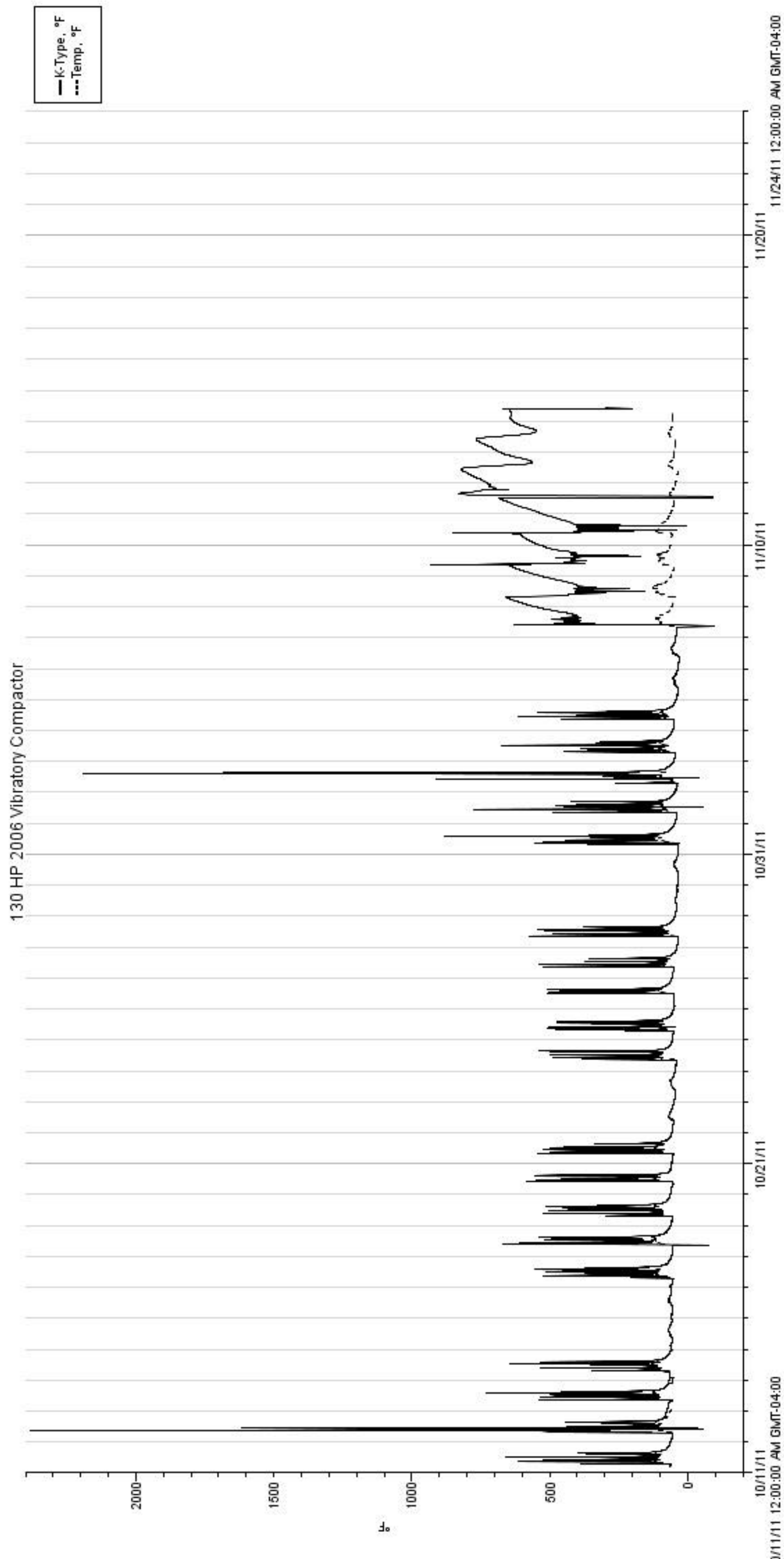
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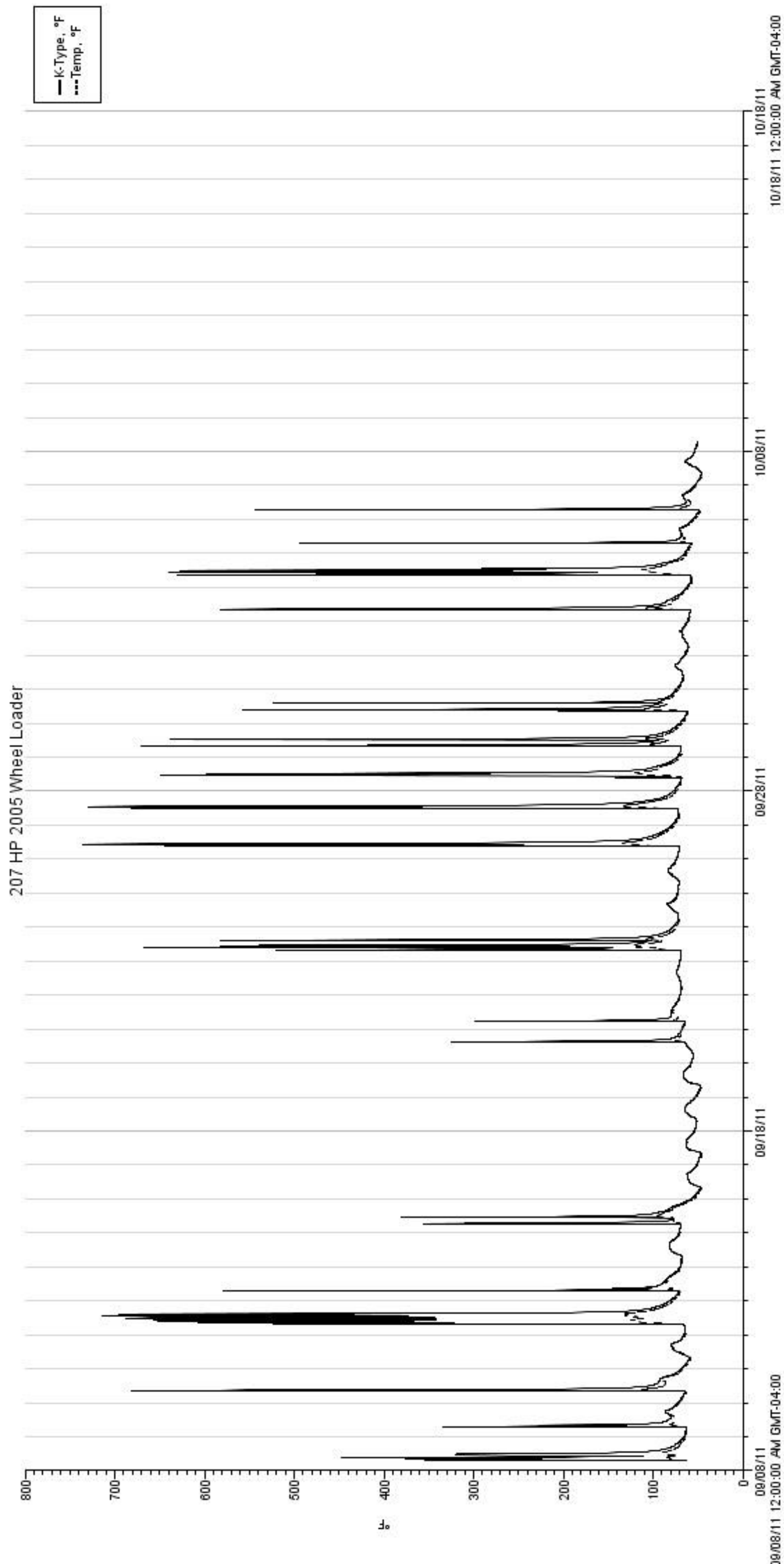
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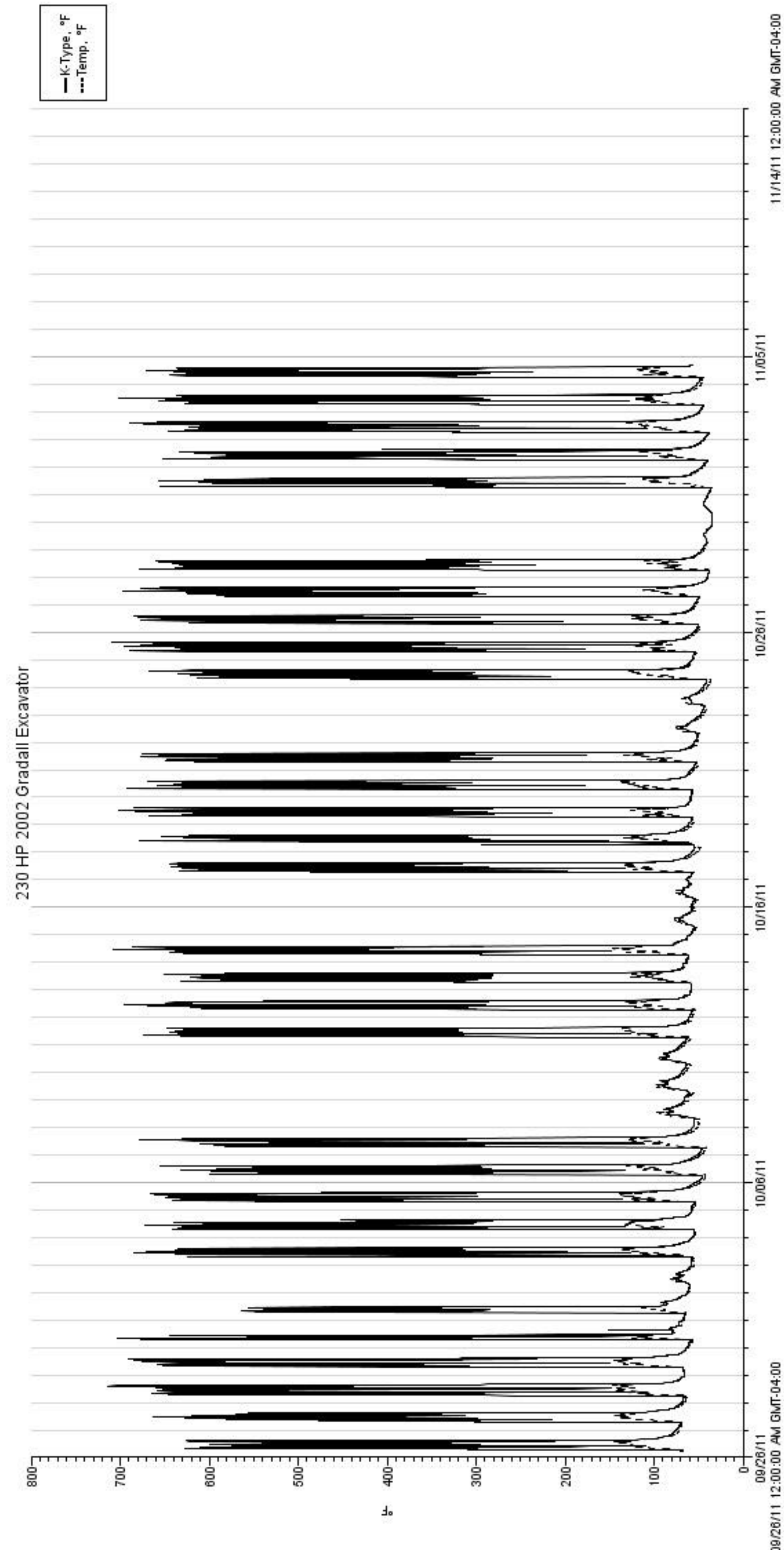
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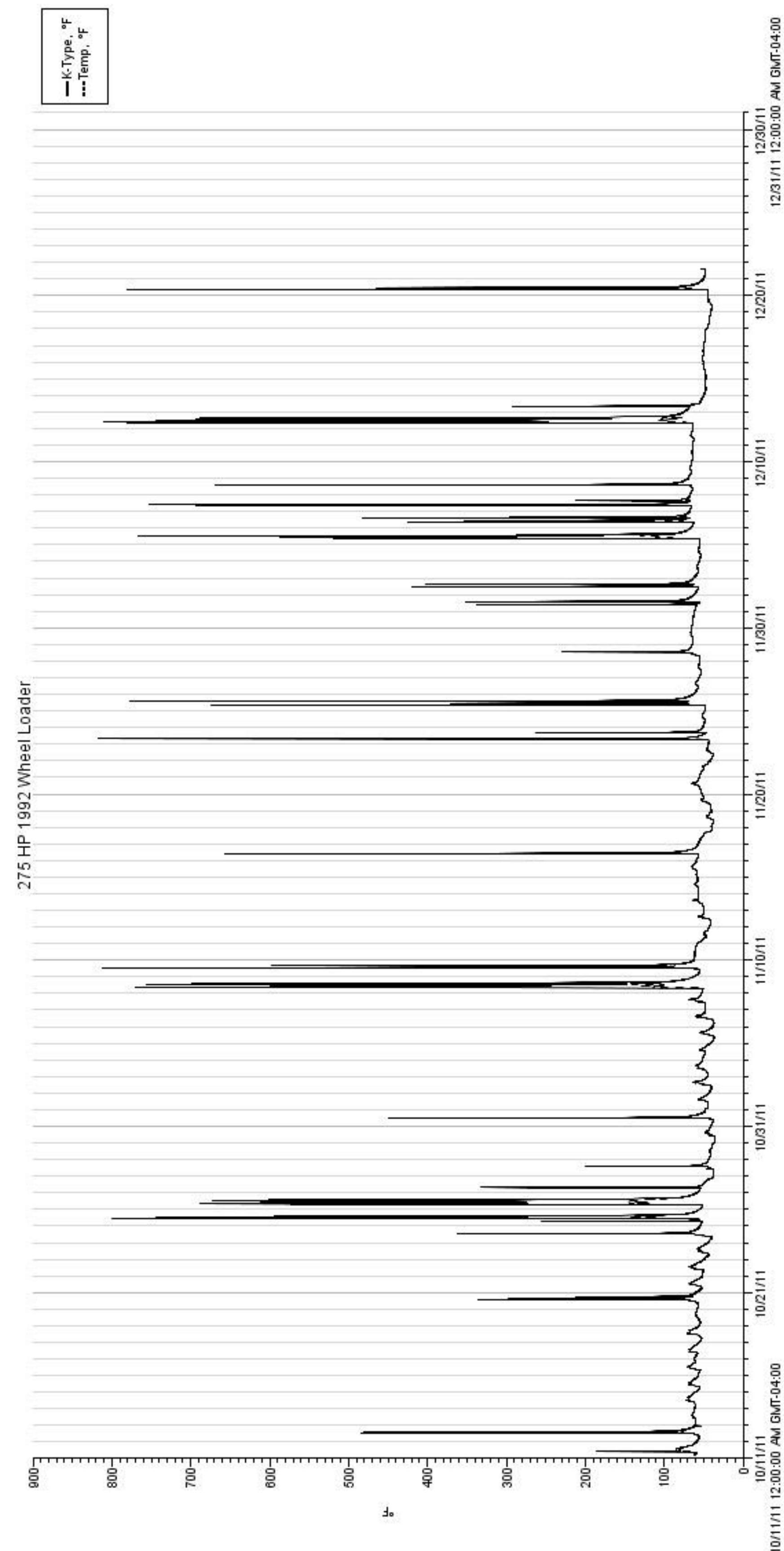
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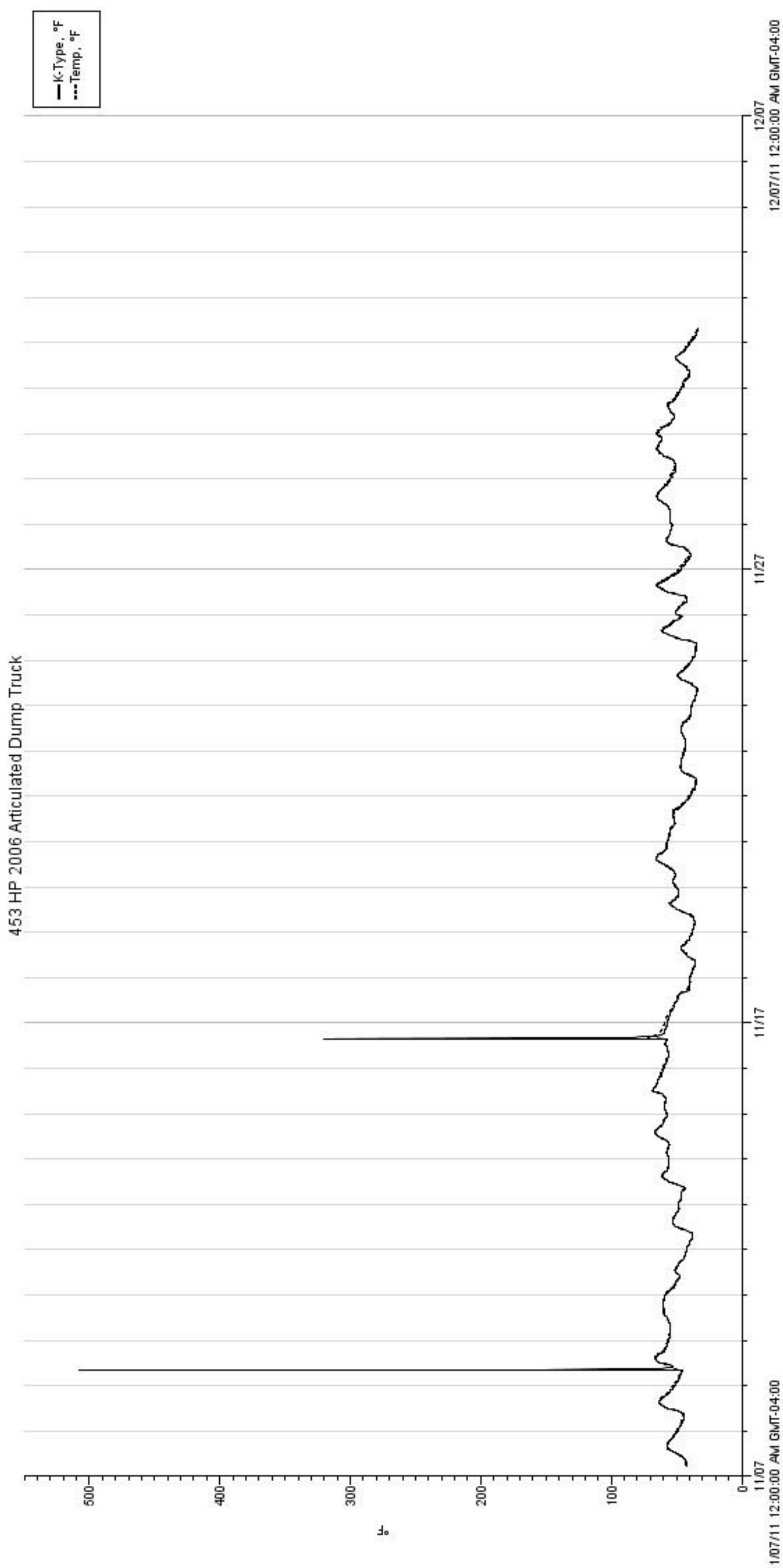
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12/07
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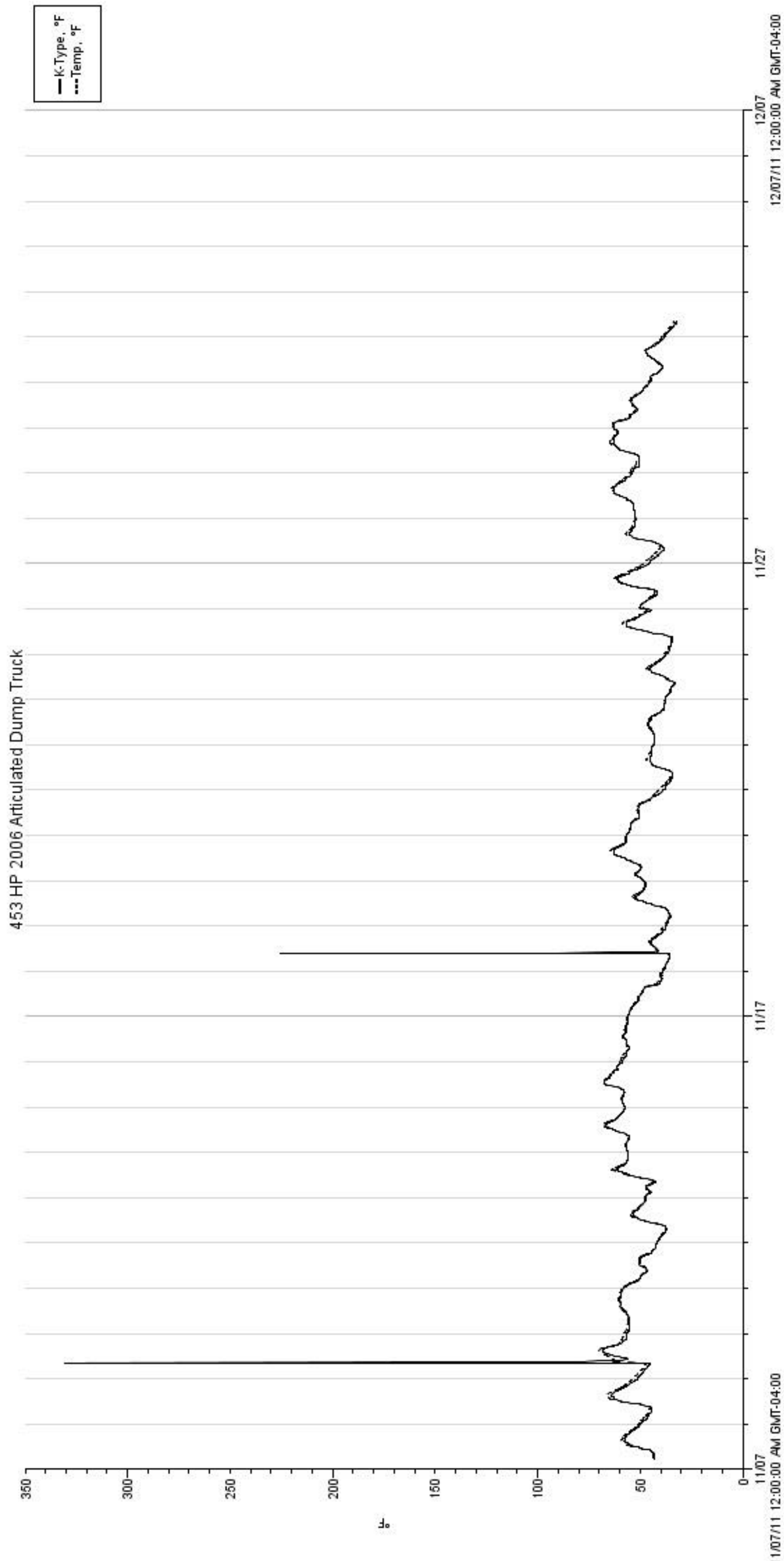
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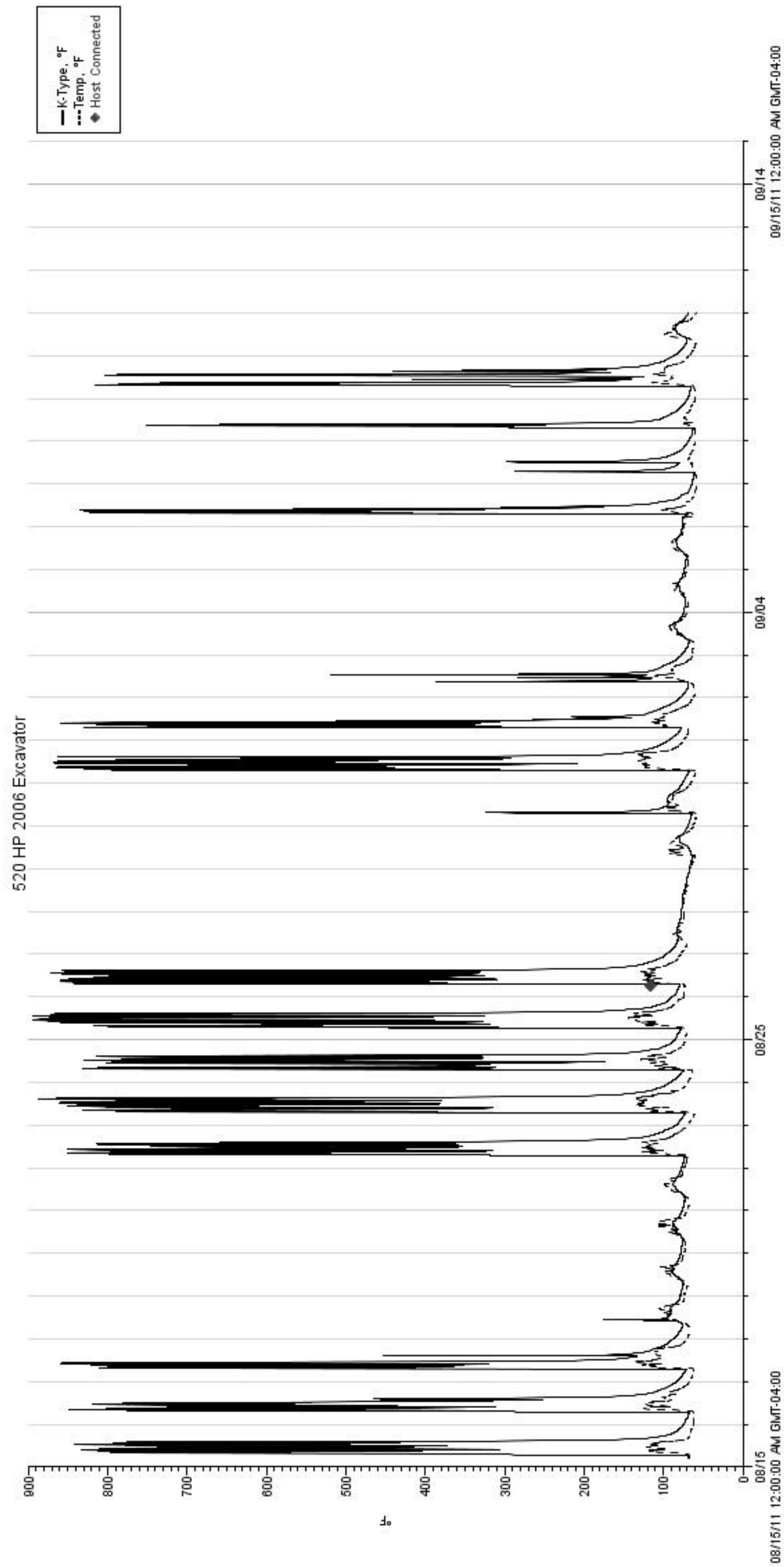
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°F
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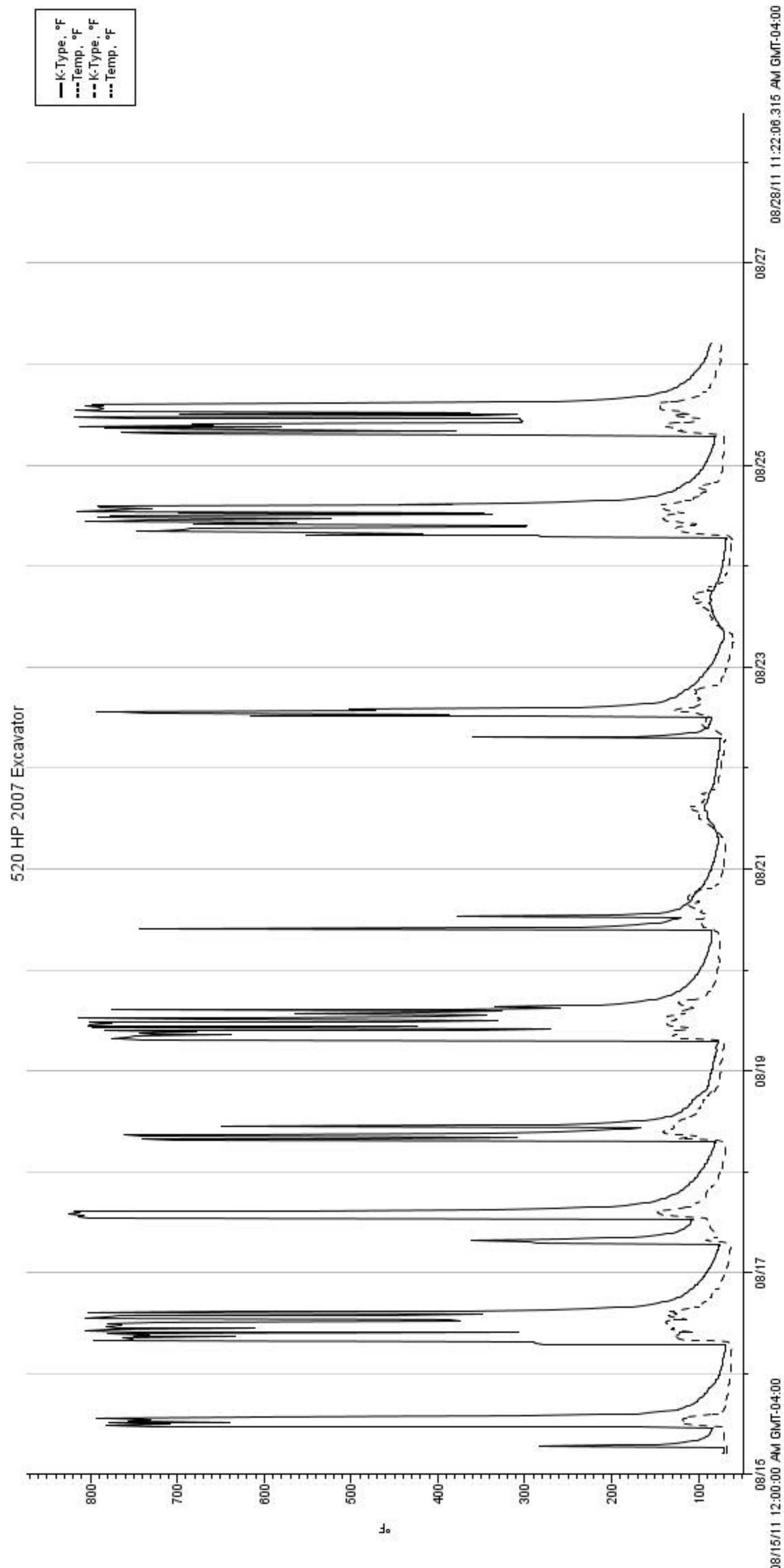
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K-Type, °F
Temp, °F
°F
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700
600
500
400
300
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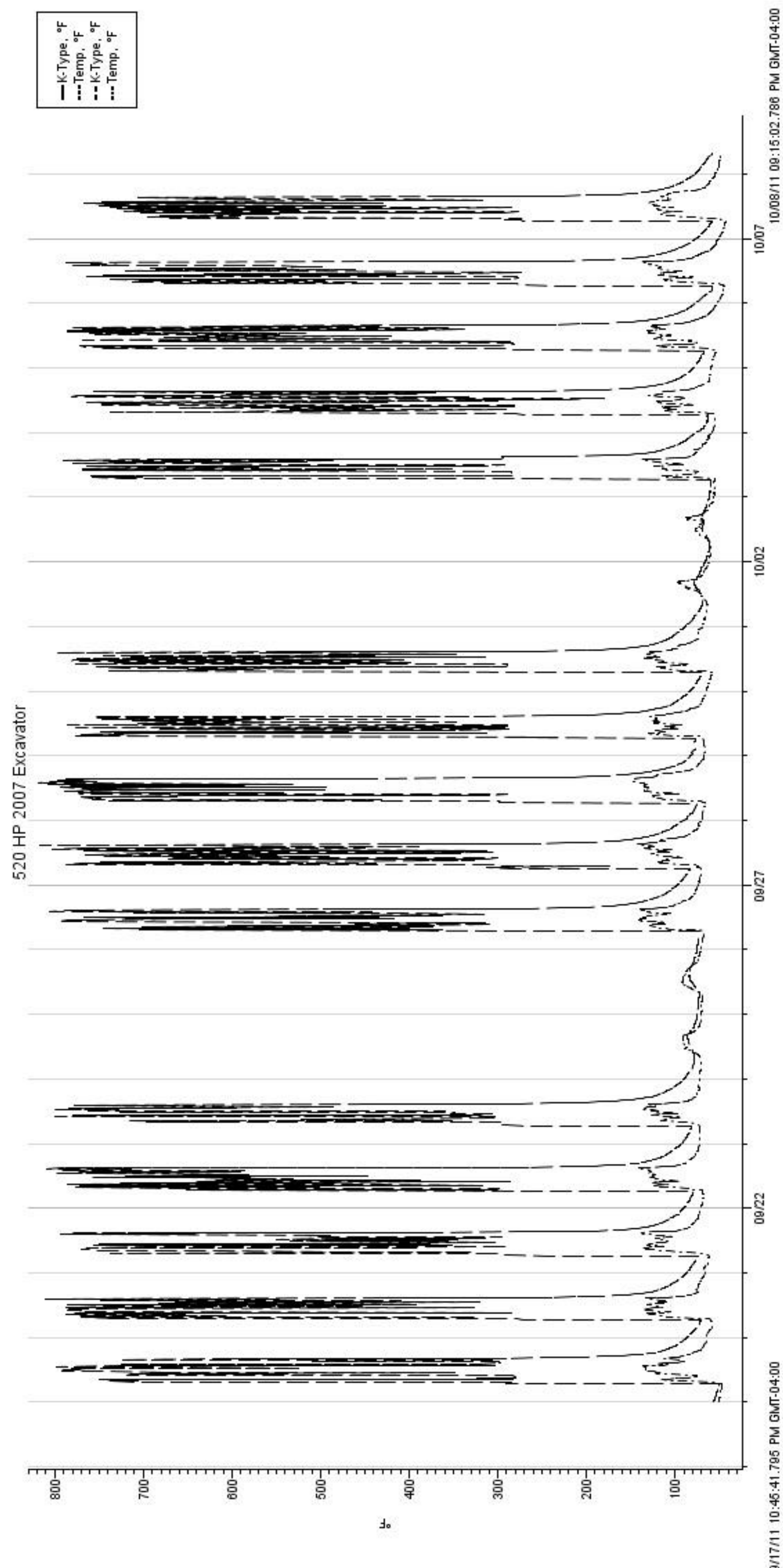
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K-Type, °F
Temp, °F
K-Type, °F
Temp, °F
°F
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200
100
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09/27
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10/07
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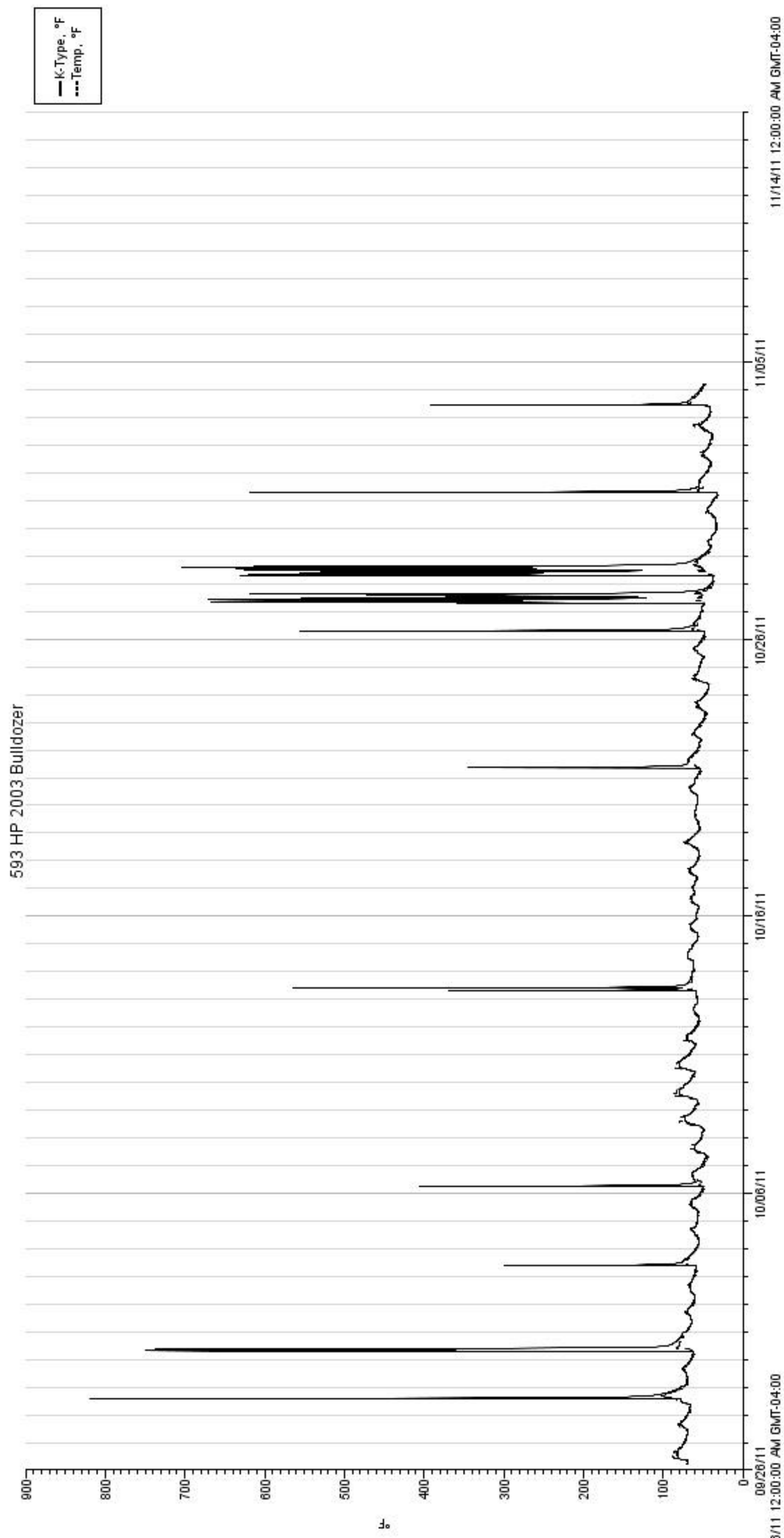
593 HP 2003 Bulldozer
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10/06/11
10/16/11
10/26/11
11/05/11
11/14/11 12:00:00 AM GMT-04:00

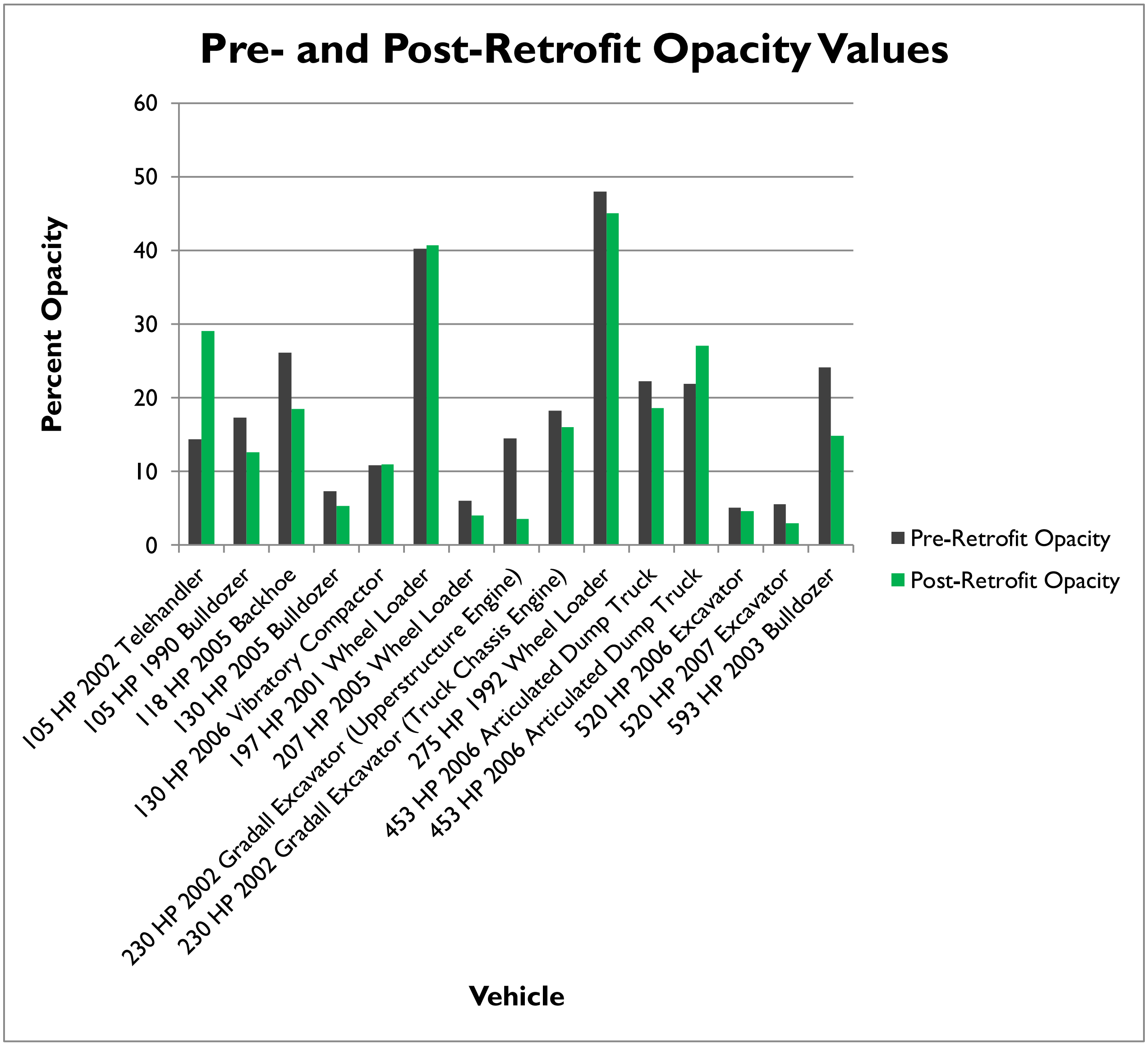
As seen in the histograms on the previous pages, some pieces of equipment were clearly used more frequently than others over the time period that the data loggers were installed. We attempted to coordinate with the project superintendent to try to time our installation of the data loggers so that they would coincide with heavier usage of the vehicles that were being monitored in order to give us better data. Due to the nature of this project, our inventory of only 6 data loggers, and our limited timeline, this was not always possible. However, we feel that we still obtained a good overall data set for the fleet.

Also, anomalies can be seen in two of the histograms above: the 105 HP 1990 Bulldozer and the 130 HP 2006 Vibratory Compactor. These errors in temperature data collection were caused by damage to the thermocouple probes that were installed on the equipment. The issue with the bulldozer was a simple loose wire that was identified and fixed, which allowed that probe to be put back into service. However, due to the large amounts of stress caused by the vibrations of the vibratory compactor, several probes were destroyed when attempting to collect duty cycle data from this vehicle. A data logger was deployed onto this piece of equipment twice, using two different methods of securing the probe. The first deployment resulted in a destroyed probe within one day of launch. While the second deployment was more successful and resulted in almost four weeks of what appears to be good, valid data, that probe was also destroyed in the process approximately three and a half to four weeks after deployment.

The individual data points that are used to form these histogram graphs was exported into Excel and used to determine the temperature duty cycle of each vehicle. Each data logger retrieved provided us with several thousand data points (10 minute read intervals running for 3-4 week deployments). In order to analyze and interpret this data, the duty cycle threshold was chosen depending on the cutoff that the retrofit manufacturer set (i.e. 280° C/536° F), and every data point that was greater than this value was counted and totaled. Next, any "non-operating" point had to be ruled out. This means that any time the engine was not running, these points should not count for or against the duty cycle. A simple estimate that we used to differentiate between "operating" and "non-operating" points is by taking the difference between the exhaust temperature and the ambient air temperature. If the difference between these two temperatures was greater than 75° F, we assumed that the engine was not on and that we could safely discard these data points. This method effectively discarded the majority of the cool-down period, after the engine had been shut off, from our data set so that it did not incorrectly decrease the duty cycle percentage by introducing data points below the threshold even though the engine was not actually running at this time and no exhaust was being produced. Finally, to determine the percent of time that the vehicle spends operating above the duty cycle threshold, the number of points above the threshold was divided by the number of total "operating" points. This number was multiplied by 100 to obtain a percent duty cycle above 280° C (or whatever the manufacturer specified minimum temperature was) out of 100%.

Pre- vs. Post-Opacity Test Analysis

The fifteen engines that received an emission control device as part of this project were all opacity tested before and after receiving their respective retrofit. Pre-opacity testing allowed us to gauge the cleanliness of the exhaust prior to any emission control device being installed and establish a baseline, as well as helping us prioritize which vehicles were in most dire need of the greatest emission reduction. As expected, the newer equipment generally exhibited lower opacity values, although the oldest engine on the project fell right in the middle of the pack in terms of opacity. Only a loose relationship was seen between older engine model year and higher opacity, with several exceptions. This was attributed to varying maintenance history or maintenance schedules for the vehicles. After installation of the retrofits, all of the equipment was re-tested in order to see how the emission reduction devices affected the opacity of the vehicles. In 11 out of the 15 engines retrofitted, a reduction in opacity was seen. There was not a strong trend to indicate that FTFs reduced opacity any more than DOCs did, despite offering double the PM reduction. Based on our knowledge that the correlation between PM and opacity is not exact enough to be an accurate metric, this did not come as a surprise. Seeing reductions in opacity was still a positive indicator overall. No change in opacity was seen in 2 of the engines retrofitted (one having received a DOC and the other an FTF). The first was a 1992 Caterpillar 950G loader at 40% opacity that received a DOC, and the other was a 2006 Caterpillar CS533E vibratory compactor at 10% opacity that received an FTF. Again, the unreliable nature of the correlation between PM and opacity led us to the conclusion that this was not a problem. There was 1 engine that exhibited a 5% increase in absolute opacity (this equated to a 23% increase relative to the vehicle's baseline reading). This increase was observed on a 2006 Caterpillar 740 articulated dump truck that received a DOC. Explanations for this increase could include the lack of a strong correlation between PM and opacity, variations in the testing environment during opacity testing (although this should be corrected by the opacity meter itself), or the most likely culprit: that the vehicle was at different stages in its maintenance cycle. For instance, a reading taken shortly after regular maintenance was performed on a vehicle could result in an opacity value that is lower (perhaps significantly so) than a reading taken shortly before regular maintenance is required. Running with dirty oil and clogged filters could very well result in the exhaust being dirtier and thus more opaque, especially when any oil is being burned along with the diesel fuel. It is important to obtain the maintenance schedules of the equipment in order to compare them with the dates on which opacity tests are performed; it was observed that this can have a noticeable effect on opacity test results. One of the tests was deemed invalid after observing a 100% increase in opacity (doubling from a baseline of 14.5% opacity to a post-retrofit opacity of 29%). Even given the potential for variances caused by the factors discussed above, this increase seems too great to be attributed to those and likely the result of human error during the baseline pre-retrofit opacity testing.



Fuel Inventory

In order to determine which vehicles were being operated the most and burning the most fuel, we maintained a fuel consumption inventory throughout the first construction season of this project using fuel slips provided to us by the contractor. Even when some of these vehicles spent time operating at other locations, we were provided fuel slips that informed us which vehicles were receiving what quantity of fuel. This data was tracked from 13 August, 2011 to 9 December, 2011, and the total fuel consumption over this period was then calculated for each vehicle by adding up every fuel delivery that occurred. Reviewing these totals made it clear which vehicles on this project were burning the most fuel and being run most often. By itself the fuel consumption data was useful in identifying the most-used equipment, but it became even more valuable to the project when used in conjunction with the opacity values observed for each vehicle. The opacity value for each vehicle served as a rough indicator of what percentage of the diesel fuel consumed by that vehicle was not being completely combusted, contributing to pollution and harmful exhaust emissions. The fuel consumption is tracking how much fuel was used overall by each vehicle during the observation period. Multiplying a vehicle's observed percent opacity by the total quantity of fuel consumed produced a pollution index for each vehicle. That pollution index was an estimate of the total quantity of incompletely combusted fuel emitted by a piece of equipment over the observation period. Calculating this value using fuel consumption and opacity values was a time-efficient method for us to inexpensively obtain a good representation of which vehicles were producing the greatest overall quantity of harmful emissions. This gave us a metric to directly compare vehicles in terms of overall pollution produced, which was very helpful when prioritizing the equipment for retrofits in general and the efficiency of those retrofits.

Mass Pollution Quantity (08132011-12092011)			
Vehicle	Total Fuel Consumption (Gallons)	Average Opacity (%)	Weighted "Mass Pollution Quantity" (Fuel Consumption * Opacity / 100)
105 HP 2002 Telehandler	112.90	14.40	16.26
105 HP 1990 Bulldozer	473.70	17.30	81.95
118 HP 2005 Backhoe	607.00	26.17	158.85
130 HP 2006 Vibratory Compactor	237.20	10.60	25.14
197 HP 2001 Wheel Loader	215.80	40.17	86.68
207 HP 2005 Wheel Loader	123.00	6.00	7.38
230 HP 2002 Gradall Excavator	1134.30	14.50	164.47
275 HP 1992 Wheel Loader	297.10	48.90	145.28
453 HP 2006 Articulated Dump Truck	117.80	20.50	24.15
453 HP 2006 Articulated Dump Truck	174.00	22.00	38.28
520 HP 2006 Excavator	2184.70	5.00	109.24
520 HP 2007 Excavator	3098.50	6.60	204.50
593 HP 2003 Bulldozer	96.60	23.80	22.99

Pre- vs. Post-Operator Surveys

Post-retrofit operator surveys were planned in order to compare with the pre-retrofit operator survey that was conducted. The intent was to note any change in vehicle performance observed by the operator. The performance of the vehicle was rated based upon the following criteria. A gain or loss in power, a gain or loss in fuel efficiency, increased or decreased noise, increase or decrease in cab odor, increase or decrease in maintenance interval or impaired operator vision.

This became an issue during the post-opacity testing because in all but one case the equipment operators had changed at some point along the time line of pre- and post-analysis. This resulted in a disruption in our survey protocol rendering our survey results inconsistent and unusable.

There was one complaint from an operator of an articulating dump truck (referred to as a Yuke), post-retrofit. The complaint stated that the cab was infiltrated with diesel exhaust fumes due to the mounting location. It should be noted that the operator of the vehicle was operating in warmer weather with the window open, which allowed the exhaust to enter the cab. This vehicle was fitted with a non-direct replacement, (FTF) that required mounting to the front fender of the vehicle and required a short exhaust stack so as not to impair the operators view. This issue was addressed by modifying the exhaust stack of the FTF.

Chapter 6: Conclusion

Comparison of Cost Effectiveness of Various Retrofit Technologies

At the inception of this project, it was our intention to identify the most cost effective emission reduction technology and rank the most common retrofit device types accordingly. As we began to research the different efficiencies of the technologies and the costs associated with each, two things became clear: the cost effectiveness of each of the three common emission control device types was fairly comparable, and there are many variables other than just cost and emission reduction efficiency that are important to consider throughout the retrofit process. After receiving bids from the various vendors for DOCs, FTFs, and DPFs, these prices were divided by the percent reduction achieved by each technology (20% reduction for DOCs, 50% for FTFs, and 85% for DPFs) to give a cost (in dollars) per percent reduction for each unit. The results of this process are shown in the table below:

Cost ($) per Percent Emission Reduction						
Vehicle	DOC	DOC	FTF	DPF	DPF	DPF
105 HP 2002 Telehandler	$131.20	$100.00	$75.72	$118.00		
105 HP 1990 Bulldozer	$131.20	$99.80	$79.96			
118 HP 2005 Backhoe	$143.30	$94.45	$79.96	$132.56	$209.66	
130 HP 2005 Bulldozer	$143.30	$99.80	$81.46	$132.56		
130 HP 2006 Vibratory Compactor	$131.20	$116.00	$100.02	$118.00		
197 HP 2001 Wheel Loader	$143.30	$144.00	$135.02	$132.56		
207 HP 2005 Wheel Loader	$143.30	$144.00	$134.92	$132.56		
230 HP 2002 Gradall Excavator	$143.30	$144.25	$135.08	$132.56	$504.71	$313.58
275 HP 1992 Wheel Loader	$243.60	$177.30	$180.08			
453 HP 2006 Articulated Dump Truck	$214.95	$221.85	$268.10	$274.16		
453 HP 2006 Articulated Dump Truck	$214.95	$221.85	$268.10	$274.16		
520 HP 2006 Excavator	$243.60	$177.05	$179.70	$272.99		
520 HP 2007 Excavator	$243.60	$177.05	$179.70	$207.22	$504.71	$299.98
593 HP 2003 Bulldozer	$243.60	$216.00	$179.70	$274.16		

The table on the previous page contains the cost per percent reduction of each unit for which a bid was received. Multiple columns for the same retrofit technology are indicative of quotes received from different vendors. Lower dollar amounts equate to a lower cost per percent reduction, and are more desirable. Low cost per percent reduction is represented with dark green shading, the average cost per percent reduction is represented with yellow shading, and high cost per percent reduction is represented by red shading. Any gradients between these colors represent intermediate values; i.e. orange shading indicates a cost per percent reduction that is higher than that of yellow shaded values, but not as high as red shaded values. The data in this table makes two important things evident. First, it can be seen that as horsepower increases (looking down each column from top to bottom) the cost per percent reduction also increases. Simply stated, this means that it will cost more to achieve the same percent reduction on vehicles with more horsepower. This is only logical, and was expected; it takes more material to construct a larger retrofit device that is appropriately sized to a larger engine. It is also important to keep in mind that larger engines will usually burn more fuel, thus emitting a greater overall quantity of pollution than a smaller engine with the same opacity value or classified in the same emissions Tier. Therefore, this immediately higher cost is actually accounted for by the removal of a greater quantity of pollutants. Removing 85% of 100 tons of PM will eliminate a greater overall quantity of pollution than removing 85% of 50 tons of PM, compensating for the increased first cost. Second, it can be seen that as the percent reduction increases across the various technology types (looking across each row from left to right), there is very little change in cost per percent reduction. This means that even though the total dollars spent needs to increase in order to increase the percent emission reduction, this increase is mostly linear, indicating that it does not cost disproportionately more to install a DPF than it does to install a DOC. In fact, based on the price quotes that we received for the various technologies, FTFs show the best trend towards having the overall lowest cost per percent reduction of the three retrofit device types. Out of all 14 pieces of the equipment assigned to this project, FTFs consistently had either the lowest cost per percent reduction or were very close behind the lowest, only being higher than the lowest by a few dollars. Because of this characteristic along with the lack of significant installation prerequisites and ease of installation of a typical FTF, this retrofit device earns the classification as the most cost effective emission reduction technology examined by this project.

Effective Retrofit Selection Process

The key components of an effective retrofit selection process are a clear definition of objectives, adequate pre-planning, and comprehensive information acquisition and analysis. Without incorporating these three components into the selection process, thorough and accurate decisions will likely not be produced, and the driving goals of the retrofit program may not be met. A clear definition of the project objectives is absolutely necessary in order to give shape and direction to the project as a whole. If there are no clearly defined objectives, it will be impossible to direct the flow of the project and evaluate its successfulness upon completion. The definition of objectives is the backbone of any retrofit project, and will form an "outline" for the progression of the project as well as criteria to determine where goals were or were not met. Pre-planning means understanding all of the work that needs to be performed throughout the project and selection process before beginning. With this understanding, all of the necessary tools and knowledge can be obtained prior to undertaking this process, and work can progress smoothly. The resolution of any snags that are encountered can then be given undivided attention since all expected work will have already been prepared and anticipated. Comprehensive information acquisition and analysis, when used in conjunction with the project objectives, is what will essentially make the retrofit selection decisions for you. Once it is known which criteria are the determining factors for selecting or ruling out a particular emission control device, examining the collected data (such as duty cycles, opacity values, and vehicle information) will definitively indicate what the best decisions are according to the stated objectives. When all three of these components are employed together, all of the guess work will be removed from prioritizing the vehicles, identifying the applicable retrofits for the vehicles, and selecting the most appropriate emission reduction solution for each vehicle. Retrofit selection should then become a seamless process.

Discussion on Significant Pitfalls Throughout the Project

The EPA, CARB and VERT programs discussed earlier in the report are all voluntary, but aid manufacturers in assuring their customers of the effectiveness and reliability of their products. It is for this reason that many mandatory diesel engine retrofit programs make EPA/CARB verification a prerequisite for any retrofit device. This is good in the sense that requiring a verified technology takes much of the risk out of the retrofit selection process and standardizes (to a degree) the quantity of reductions being achieved. It can however limit the selection of technologies that are available to be purchased. A major flaw in requiring verification of emission reduction technologies is that if a manufacturer cannot afford to put their product through the costly verification process, or if a verified technology for some reason loses its verification that product will automatically be excluded from use even if it is the best and cheapest product on the market. This is especially true of any new or revolutionary products that may hit the market, be guaranteed by the manufacturer, but have not yet met the lengthy verification requirements. Major emission reduction technology manufacturers will have a written certification, backed by test data and results that will guarantee the performance and longevity of their product. When purchasing emission reduction technologies, it must be decided whether to require EPA/CARB verification, require any major verification, only use verification as a guide, or accept manufacturer certification as adequate assurance.

The construction company equipment superintendent was asked to compile a fleet inventory of all equipment to be utilized on the project. An excel spread sheet was provided to the equipment superintendent that enabled listing all pertinent information needed on each piece of equipment to aid in the determination of choosing the correct retrofit technology and to properly format our test equipment for the deployment and recovery of data. It was imperative for us to physically inspect each vehicle engine label located on the engine block to manually verify the inventory information since much of the vehicle information that the contractor had on file was incomplete or incorrect. This allowed us to create a vehicle inventory list that we knew was 100% accurate. The manual verification of the engine label information revealed that much of the data provided was incorrect. In some cases an alpha or numeric character was missing and in others engine family numbers and vehicle identification numbers were transposed or not present at all. It is very important to verify all of this information and ensure that it is accurate and matches the vehicle identification or registration number.

In order to determine which vehicles were being operated the most, burning the most fuel, and burning the correct fuel (red dyed ULSD for any strictly off road vehicle) we maintained a fuel consumption inventory throughout the first construction season of this project using fuel slips provided to us by the contractor. We were provided fuel slips that informed us which vehicles were receiving what quantity, type and at what project site the fuel was dispensed into the vehicle. This data was tracked from 13 August, 2011 to 9 December, 2011, and the total fuel consumption over this period was then calculated for each vehicle.

It was our intention to continue with this process when the second construction season got under way in the spring of 2012. This became a problem because many of the pieces of equipment had completed their intended services on the Waterfront Drive Project and had been moved onto another project site. While fuel slips (including fuel type) for these vehicles were collected by the contractor, they were spread out over a number of various construction projects. This meant that the fuel was consumed on other projects, making the fuel consumption data irrelevant for the purposes of the pilot project. The type of work done by the equipment on other projects varied from what was seen on the Waterfront Drive Project. However, it can be safely assumed that the overall quantity of fuel consumed by each vehicle will remain fairly consistent long term. We did not observe any violations of any fuel requirements, including the use of ULSD and the appropriate use of red dyed ULSD throughout the life of the project. The pieces of equipment that moved off site had already met the 30 consecutive construction days on the pilot project sight and therefore qualified to be retrofitted. In some instances a piece of equipment would come back onto the pilot project site but usually only for several days.

Feasibility and Impact of the Diesel Emission Reduction Act

It is our finding that implementation of the Diesel Emissions Reduction Act is completely feasible. This is with a slight increase in the overall cost of construction projects ranging from (1%~2.5%). This increased cost to construction would include the cost of purchase, installation and any pre- or post-monitoring required to verify the installation and its efficiency. Reimbursable funding under the federal highway grants program will have to be adjusted to reflect this increase until such time that the legacy fleet is completely retrofit or retired.

The cost and implementation of an off road diesel emissions reduction program is scalable and would have a negligible impact on the construction industry if financed as part of the construction cost. There would be no direct cost to the construction industry under this format.

A substantial positive environmental impact would be realized with a wide range of results. Depending on the type of retrofit technology chosen for each construction project, a range of reduction on air quality pollutants would be realized. The range of reduction is 20 to 90% compared to uncontrolled emission levels of the legacy fleet. These estimates are based upon verified EPA and Carb emissions technology minimum reduction standards by technology type. For example, if the entire legacy fleet of construction equipment was retrofitted with DOCs, an overall 20% reduction would occur, and if all were retrofitted with DPFs, an overall 90% reduction would likely occur.

Considerations for Developing Off Road Diesel Emission Legislation

1. Review existing local, state and federal legislation.
2. Review and address shortcomings to existing legislature. A review of the Rhode Island legislation in included.
3. Be wary of contradictory statements within existing law.
4. Better define what constitutes “disproportionate polluter”?

5. Consider tightening vehicle eligibility requirements to qualify for mandatory retrofits.

6. Better define departmental authority and enforcement responsibilities of this legislation, and ensure they are adhered to.

Suggestions for Future Research Projects

1. Develop and maintain a database inventory of the state's legacy fleet.

2. Develop and maintain a data base inventory of the state's retrofitted vehicles.

3. Perform an alternative fuels and fuel born catalysts study pertaining to further diesel emission reduction.

Appendix A - A Road Map for Diesel Emission Reduction in Rhode Island

Introduction

Cleaning up diesel pollution to improve air quality is an important goal throughout New England states where respiratory disease has reached historic levels. Diesel engines produce significant air pollution including fine particulate matter (PM), nitrogen oxides (NOx) and more than 40 different types of Hazardous Air Pollutants (HAPs). Diesel emissions have been linked to a myriad of health problems ranging from shortness of breath to cancer and cardiac arrest. Construction equipment engines typically produce more diesel emissions than other diesel engines because their engines are larger and are not regulated as strictly.

The Environmental Protection Agency (EPA) has mandated that by 2010 the sulfur standard for diesel fuel will be 15 ppm for all construction vehicles. In addition, EPA regulations require that new engines meet standards that will make them more than 90 percent cleaner than older construction equipment. However, these standards will affect only newly manufactured engines and will not reduce emissions from older vehicles and equipment.

Because the federal regulations only apply to newly manufactured diesel engines, state and local regulatory bodies and public agencies have joined forces to develop programs, regulations and policies to reduce diesel emissions. Several states and some municipalities have enacted legislation mandating diesel engine retrofits according to a specified timetable and degree of emission control. However, in many cases enforcement of the regulations has been delayed, pending additional information on the costs and benefits of the regulations. As an alternative to further mandates, the EPA, in cooperation with state and regional diesel pollution control groups, has developed a program called Clean Construction USA, an extensive financial and technical assistance program to assist owners and operators of construction equipment to reduce emissions from the older engines that are in operation today. In addition, the Northeast Diesel Collaborative has developed a suite of programs to assist with emission reduction efforts under way by private and public sector fleet operators.

The purpose of this project is to capitalize on the wealth of both experience and funding available at the state and federal levels to accelerate and facilitate reduction of diesel pollution from work performed on projects managed by the Rhode Island Department of Transportation (RIDOT).

The project included the development of **"A Road Map for Diesel Emission Reduction in Rhode Island".** This component of the project is designed to guide the State of Rhode Island through the process of implementing future diesel emission reduction strategies for off road heavy duty construction equipment, specifically legacy fleets. The implementation and monitoring of diesel emission reduction strategies on RIDOT-funded construction projects is governed by the State of Rhode Island general law "The Diesel Emission Reduction Act". Mandated by this act is the implementation of diesel emission reduction strategies, monitoring, accounting, and reporting of off road diesel fleet retrofits. This "Road Map" provides a straightforward how-to guide designed to provide the necessary direction throughout the retrofit process.

Legislative Requirements

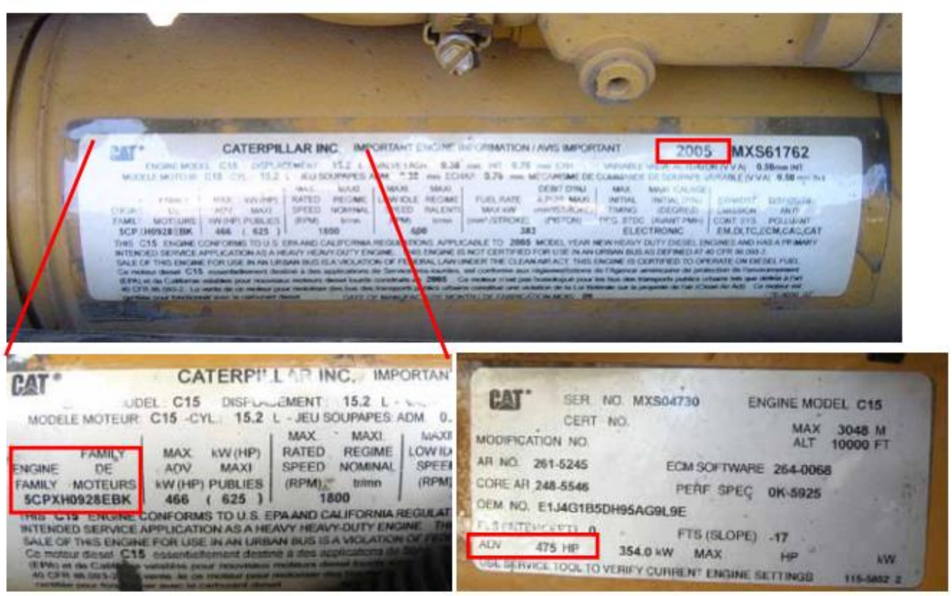
Within the Diesel Emission Reduction Act, it is mandated that "Beginning January 1, 2013, any solicitation for a public works contract or contracts with the stated funded in whole or in part by federal monies and having a total project cost of at least five million dollars ($5,000,000), and any contract entered into as a result of such solicitation, shall include provisions requiring all heavy duty vehicles used in the performance of such contract to adhere to the following requirements:". The requirements referenced by this clause state that any heavy duty vehicle that is used on the project for thirty or more total work days (with some exceptions such as emergency response vehicles, etc.) shall be powered by engines with properly operating and maintained emission control devices of the highest applicable Level of reduction, to the extent of available reimbursement from project funds covering the equipment purchase and installation. The legislation also states that "Construction shall not proceed until the contractor submits an equipment list of all heavy-duty vehicles to be used on site, in the format specified by the department of environmental management,". This equipment list is required to include such information as contractor and subcontractor contact information, documentation and verification of any retrofit devices already installed on equipment, or proof of purchase and expected ship date for retrofits not yet installed. Any vehicles on this list that are to be used on an eligible project that are not already retrofitted or do not yet have a retrofit device on order may not be used on the project site until such time that at least one of these two requirements is met. Noncompliant equipment for which a retrofit has been ordered may operate on site for a maximum thirty total work days to allow ample time for delivery and installation of the retrofit. It is also provided that "The contractor shall submit monthly summary reports to the project manager, updating the equipment list, including diesel fuel use for the reporting time period for all equipment used in the performance of the contract. The addition or deletion of any equipment shall be included in the summary and noted in the monthly report".

Since there is little experience in the retrofitting of off road diesel heavy duty and construction equipment, this document will serve as a guide to outline the process that will now be required by state law on all applicable upcoming public works contracts.

Determining Applicable Equipment

The first step in determining what vehicles are eligible and required to receive retrofits is to compile a fleet inventory list containing all of the heavy duty vehicles that will be used on the project for thirty or more total work days. This list is very important in the retrofitting process, and will be used from start to finish. Using the equipment list that the contractor is required to submit prior to construction beginning, the contractor should be consulted to establish which of the vehicles on this list will be on site for thirty or more total work days. The vehicle inventory list will be one of the most important documents in this process; the contractor should verify and double check all of the vehicle information before progressing any further. All vehicle information on file (especially Engine Family Numbers) should be physically verified from each vehicle's engine name plate. Engines manufactured prior to 1996 will not have an Engine Family Number (EFN). A sample engine name plate is shown below, indicating where some of the important vehicle information may be located. A sample fleet inventory list is shown on the following page, listing the critical information that needs to be gathered about each piece of equipment. Identifying vehicle information has been censored in this sample to protect the confidentiality of the General Contractor from which this information was gathered.

Caterpillar Engine Example:



Caterpillar Nameplate (2 labels): EPA Family Name – 5CPXH0928EBK
Engine Model Year - 2005
Engine Horsepower – 475 HP

Applicant Fleet Description Spreadsheet

by Your Agency to Identify the Vehicle	Vehicle License Plate Number	VehicleType (School bus, utility vehicle, dump truck, waste hauler, etc.)	Vehicle Identification Number (VIN)	Vehicle Model Number	Engine Make	Engine Model	Engine Family (listed on engine label)	Engine Serial No.	Engine Model Year	Engine Horsepower	Average Annual Miles	Average Annual Hours	Average Operating RPMs	Muffler Model Number
Example # 999	ABC-123	Refuse Truck	1HTSDAAN6SH635101	321F	International	DT466HT	3NVXH0365F	1823820C1	2003	195	8500	1800		
		Gradall Excavator		XL 5100	Cummins	6BTA59-C173 (C8.3-C)	2CEXL0359ABA, 2CEXL0505ABB (on-road)		2002	230			2100	
		Backhoe		710G	John Deere	6068TT057	5JDXL06.8041		2005	118			2200	29161A REV E
		Track Excavator		345C	Caterpillar	C-13	6CPXL12.5ESK		2006	520			2100	
		Articulated Dump Truck		740	Caterpillar	C-15	6CPXL15.2ESK		2006	453			2286	CAT 231-7645
		Articulated Dump Truck		740	Caterpillar	C-15	6CPXL15.2ESK		2006	453			2286	CAT 231-7645
		Wheel Loader		980F	Caterpillar	3406B	N/A		1992	275			2100	CAT 7N-9674
		Wheel Loader		950G	Caterpillar	3126DITA	1CPXL07.2MRB		2001	197			2200	
		Wheel Loader		IT62G	Caterpillar	3126DITA			2005	207			1950	CAT 216-1678
		Bulldozer		D8R Series II	Caterpillar	3406E	3CPXL14.6ESK		2003	593			2100	
		Track Excavator		345C	Caterpillar	C-13	7CPXL12.5ESK		2007	520			1800	
		Vibratory Compactor		CS533E	Caterpillar	3054C (2176/2200)	6PKXL04.4RJ1		2006	130			2200	
		Bulldozer		D5N	Caterpillar	3126	5CPXL07.2HSK		2005	130			2000	
		Bulldozer		D4H Series II	Caterpillar	3204DI	N/A		1990	105			2000	CAT 112-1665
		Telehandler		TH103	Caterpillar	3054	2PKXL03.9AK1		2002	105				197-9717

All of the identifying vehicle information has been censored to maintain confidentiality on behalf of the participating General Contractor.

After obtaining and verifying this information, the next step is to check for any exemptions that might rule out vehicles on this list from being required to receive an emission control device. According to the legislation, these exemptions include: vehicles and equipment dedicated for snow removal; farm equipment; vehicles that are specifically equipped and used for emergency response and vehicles that are used during a declared state of emergency and for the life of the project associated with the state of emergency; vehicles that are used to deliver equipment or material to and from the project site; standby generators; and unregulated, or pre-Tier 1 diesel engines (pending determination from DEM to determine how to reduce particulate emissions from these engines). When all allowable exceptions have been eliminated from the inventory list, the remaining vehicles should be all of those on the project that are eligible and required to receive an emission control device.

Determining the Appropriate Retrofits

Once the eligible equipment inventory list has been finalized, it is time to proceed to selecting the appropriate retrofit layout for each vehicle on that list. According to the Diesel Emission Reduction Act, vehicles meeting the eligibility requirements "shall be powered by engines with properly operating and maintained Level 3 controls", meaning that where possible, an emission control device with 85% or greater efficiency (such as a Diesel Particulate Filter or DPF) must be installed. Exemptions are made when this is not feasible: "Provided, however, that if the department of environmental management (DEM) finds that no Level 3 verified emission control devices have been verified and are otherwise appropriate for use on particular engines, Level 2 verified devices shall be required; if neither Level 3 nor Level 2 devices have been verified and are otherwise appropriate for use on particular engines, Level 1 verified devices shall be required". This holds with the standard "Best Available Technology" practice for retrofitting diesel vehicles, meaning that the emission control device with the greatest efficiency that is feasible to install on a particular vehicle must be selected. The feasibility of a device that is to be installed on a vehicle is determined through testing discussed later in this section. A visual "decision tree" has been developed that illustrates the retrofit decision making process in flowchart form, specific to the legislative requirements set forth by The Diesel Emission Reduction Act. This decision tree is included at the end of this Road Map.

Technically, given today's passive and active DPF technology, nearly 100% of heavy duty diesel vehicles can receive Level 3 controls. However, on many vehicles these devices may not be "appropriate for use" due to size, cost, obstruction of vision, or adverse effects on the intended operation of the equipment. These factors should be referenced and evidence must be provided to substantiate these claims if a lower Level device is desired on one or more pieces of equipment eligible for retrofit.

Since the legislation calls for Level 3 devices on all vehicles when feasible, it is first important to determine whether or not each vehicle can effectively be equipped with a passive DPF or whether it will require an active DPF. This must be determined by pre-testing each vehicle and obtaining the temperature duty cycle of each eligible vehicle as well as pre-testing opacity to ensure the vehicle does not exceed the maximum allowable opacity value for use with a particular retrofit device. Ensuring that this testing is performed and analyzed is the responsibility of the Contractor, and it is something that will likely be performed by the winning bidder who will be supplying and installing the retrofit devices. The cost associated with the testing can either be a separate charge, or may be incorporated into the overall retrofit parts and labor cost. The temperature duty cycle of a vehicle is the profile of the temperature of the exhaust stream observed directly prior to entering the muffler over a substantial period of time. This duty cycle can then be analyzed to determine whether or not a vehicle meets the manufacturer's requirements for a passive DPF to operate properly. The typical duty cycle requirements for a passive DPF will be something in the range of "at least 260° C for at least 40% of the time the vehicle operates" but will vary between individual devices. Once this analysis is complete, identify all vehicles that are able to successfully run a passive DPF; these should receive the highest priority to be retrofitted. All eligible vehicles that do not meet the passive DPF requirements should be allocated to receive an active DPF. For any vehicles that are believed to be unable to feasibly receive an active DPF retrofit, proper supporting evidence should be provided to DEM in order for a final determination and potential allowance of a lower Level device. It is wise to ensure that verified devices are available for all vehicles to which a passive or active DPF retrofit is assigned. A good way to do this is to use the Engine Family Number from each vehicle in question obtained during compilation of the equipment inventory list to search CARB's Verification Database: <http://www.arb.ca.gov/diesel/verdev/vdb/vdb.php>.

If it is found that neither a passive nor active DPF is appropriate for use on one or more of the eligible vehicles, a Level 2 device achieving emission reduction of 50% or greater (such as a flow-through filter or FTF) must then be considered for each of these vehicles. FTFs are much more universally applicable than DPFs, and there is rarely a case where an FTF is not feasible for a piece of equipment. The first thing to check, as with a DPF, is the temperature duty cycle of the vehicle. FTFs also have a duty cycle requirement, but it is much lower than that of a passive DPF and is easily met by nearly all heavy duty diesel vehicles. The typical duty cycle requirements for an FTF will be something in the range of "engine exhaust temperatures at the filter inlet of at least 280° C for at least two minutes each hour of operation to ensure adequate regeneration" but will vary between individual devices. Most FTFs are now able to be constructed as a direct replacement device (exactly mimic the size and shape of the original muffler) or at least be made to fit in the compartment where the original muffler was housed. Even when this is not possible FTFs are still generally much smaller in size than a DPF for a comparable engine, so the prohibitive issues associated with DPFs are usually completely alleviated by FTFs. For any vehicles that are believed to be unable to feasibly receive an FTF retrofit, proper supporting evidence should be provided to DEM in order for a final determination and potential allowance of a lower Level device. It is wise to ensure that verified devices are available for all vehicles to which an FTF retrofit is assigned. Again, this can be done using the Engine Family Number from each vehicle in question and the link to CARB's Verification Database above.

If a passive DPF, active DPF, and FTF are all found to not be appropriate for use on one or more of the eligible vehicles, a Level 1 device achieving emission reduction of 25% or greater (such as a Diesel Oxidation Catalyst or DOC) must then be considered for each of these vehicles. Both EPA and CARB also verify certain fuel additives and alternative fuels as Level 1 controls. It is extermely rare that a post-Tier 1 heavy-duty vehicle would not be able to have a DOC installed. The requirements for a DOC are minimal: essentially only needing to achieve at least 150° C at some point during its duty cycle, be well maintained, and not be equipped with an oil burning system or have lube or other oils mixed in with the fuel. DOCs are almost always made as direct replacement devices and will exactly replace the original muffler. If an extremely rare case does arise in which a DOC is deemed not appropriate for one or more vehicles, one of the verified fuel additives (PuriNOx or Viscon) will likely work. In addition, a blend of biodiesel may be used with any diesel engine in order to achieve emission reduction, but is currently only verified by EPA for on road use.

Retrofit Budget

Once the layout of retrofit devices has been completed for all eligible vehicles, the available budget specified by the state must be taken into consideration. Given that the legislation states that "Emission controls shall be required only to the extent of available reimbursement from project funds covering the equipment purchase and installation labor costs of the controls, provided that at least one percent (1%) of the total of each project budget shall be dedicated for such reimbursement", it is likely that decisions will need to be made to prioritize the eligible vehicles to decide which will receive retrofits and which will not. This responsibility falls to the General Contractor, and the decision must be made based on several specific factors: "Contractors shall give priority to retrofitting vehicles and equipment that: (i) Will likely spend the most time operating on the project; (ii) Will disproportionately expose the surrounding community and sensitive receptors including, but not limited to, hospitals, schools and residential neighborhoods to diesel pollution; and (iii) Are most cost-effective in terms of emission controls for particulate pollution reduction per dollar spent". The first factor is self-explanitory, but the second and third may seem confusing or difficult to determine. Factor (ii) is referring to vehicles that pollute more than others. Having the winning bidder conduct testing for pre and post duty cycle temperature, opacity and fuel consumption analysis is a good way to gain insight into which vehicles produce the highest quantity of pollution. The fuel consumption of the vehicles will help to determine which vehicles are combusting the highest quantity of diesel fuel. By examining both of these aspects in conjunction, a simple and accurate metric is obtained for comparing the mass quantity of pollution emitted by each vehicle. Factor (iii) may have several interpretations. First, it may be assumed that this factor is referencing the cost effectiveness of the various retrofit technologies in terms of dollar cost per percent reduction. It has been observed that the cost per percent reduction is similar between DOCs, FTFs, and DPFs for the same piece of equipment, so unless the specific bids received indicate otherwise this interpretation is moot. Alternatively or in addition to this first interpretation, factor (iii) may suggest that it is not cost effective to spend money installing a potentially very expensive retrofit device on a vehicle that may be retired prior to reaching the end of life of the retrofit device itself. The age and condition of the vehicles to be retrofitted should be taken into consideration when assigning priority to the eligible vehicles. As many of the eligible vehicles as allowable by the budget should then be retrofitted, starting with DPFs and then progressing down the list from highest to lowest priority until all available funds have been expnded or every eligible vehicle has been retrofitted. In the event that all eligible vehicles are able to be retrofitted within the constraints of the budget, the legislation provides that "Dedicated funds…remaining after all eligible vehicles and equipment have been retrofit and reimbursement to contracters has been rendered subject to the provisions of this statuate, may be considered part of the overall project budget as determined by the state".

Bidding, Purchase, and Installation

After the retrofit selection layout has been finalized, the bidding and purchase process may begin. The State of Rhode Island Department of Environmental Management Air Quality Division has previously issued a Request for Proposals (RFP) to establish a preapproved bid list of qualified diesel emission retrofit installers for a state wide school bus retrofit program. These six preapproved vendors include Southworth Milton Caterpillar, Shuster Corporation, Ballard Mack Truck Center, DATTCO Incorporated, New England Detroit Diesel Allison, and Pascale Service Corporation. This preapproved bidders list can serve as a starting point for a list of qualified installers to which the construction project retrofits bid requests may be sent. However, because they were approved for school bus retrofits, not all of the vendors expressed confidence in off road construction equipment retrofits. After the bids are received, reviewed, and the sales awarded to one or more vendors, installation of the retrofits can begin as soon as the necessary parts arrive. The availability of emission control devices will depend greatly on the level of demand around the time they are being purchased. Due to the rarity of the precious metals being used in these devices, there will always be some delay in production and distribution. Many retrofit manufacturers also custom manufacture each and every retrofit device, so this too will add some time between ordering and receipt of the product. The delay on DOCs will usually be the shortest, followed by FTFs and passive DPFs in the middle, while active DPFs will most likely come with the longest delay. It is wise to allow for at least 4-6 weeks between the time the components are ordered and when they are received. Ultimately, the vendor or manufacturer should be consulted, as they will have a more accurate estimate at the time of purchase.

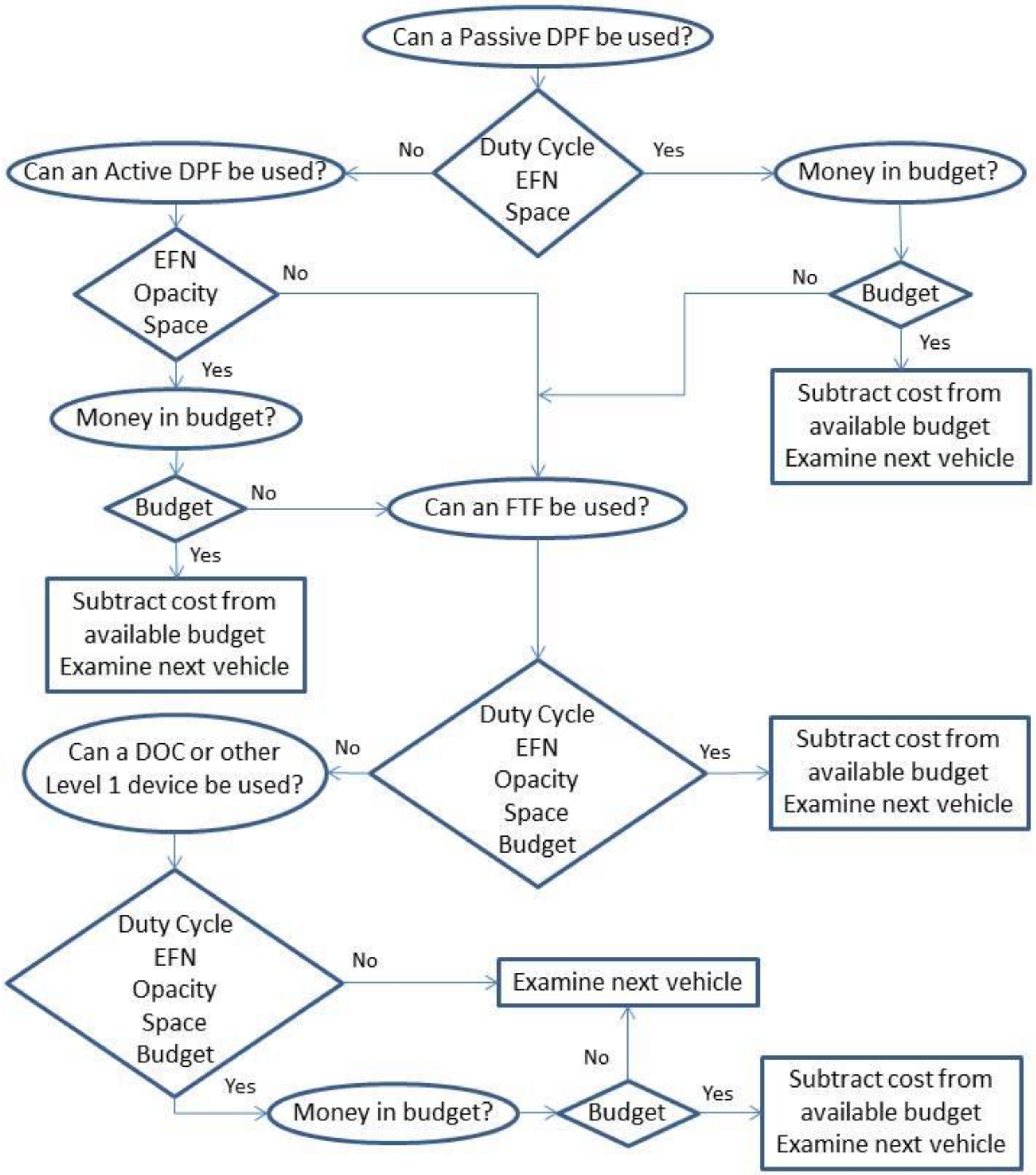
Different manufacturers and vendors will have different policies regarding who is authorized to install their devices, but most often the case will be that an authorized installer will need to be the one performing the installations. This authorized installer is often the vendor through whom the emission reduction technologies are purchased. If the customer is in a situation where they feel capable to perform the installations themselves, the manufacturer might be willing to work with the customer to allow this. However, in most cases the retrofit installations are performed by a third party. The length of every installation will vary, depending greatly on the complexity. Added complexities in an installation can be caused by any number of factors from difficulty of accessing the muffler to designing, fabricating, and adding components to the equipment. These complexities will most often be experienced with non-direct replacement FTFs, and passive and active DPFs. With FTFs and passive DPFs, the challenges will usually be limited to things like locating and potentially reinforcing an alternate mounting location if the device will not fit where the original muffler was located, and rerouting the exhaust piping if necessary. With active DPFs, the above challenges are more likely, as well as having to route and install additional fuel lines or electrical wiring for the afterburner component of the active DPF. The average retrofit installation will take approximately 1-3 hours for a DOC, 2-5 hours for an FTF, 15-30 hours for a passive DPF, and 20-40 hours for an active DPF. DOC installations and most FTF installations will usually be able to be done in the field, while more complicated FTF installations and almost all DPF installations will need to be done within the proper facility.

Post-Installation Considerations

After the devices have been installed, documentation including the technology type, EPA/CARB verification number/control Level, manufacturer, make, model, serial number of the retrofit device, and the date the retrofit was installed should all be obtained and recorded. This documentation will be needed as proof that the equipment has been retrofitted in order to satisfy the requirements of the legislation, and will need to be submitted should the equipment be eligible to be used on any future public works projects.

Also, the legislation outlines the General Contractor's reporting responsibilities over the course of the project: "The contractor shall submit monthly summary reports to the project manager, updating the equipment list, including diesel fuel use for the reporting time period for all equipment used in the performance of the contract. The addition or deletion of any equipment shall be included in the summary and noted in the monthly report". The legislation also dictates the fate of retrofits installed on equipment as part of this Act: "Retrofits installed with funds from the project shall remain on the heavy-duty diesel vehicle for the useful life of the emission control device or the vehicle or in the event the vehicle is sold out-of-state the retrofit technology may be removed at the contractor's expense and used on a piece of equipment that performs work within Rhode Island no later than one year from the date it was removed from the original equipment".

Legislative Requirements: Vehicles shall be powered by engines with Level 3 controls. If no Level 3 verified emission control devices are deemed appropriate, Level 2 verified devices shall be required; if neither Level 3 nor Level 2 devices are deemed appropriate, Level 1 verified devices shall be required. Contractors shall give priority to retrofitting vehicles and equipment that will spend the most time operating on the project, are the greatest polluters, and are most cost effective for pollution reduction per dollar spent.



Appendix B - Existing Rhode Island Legislation Pertaining to Diesel Emission Reduction in Construction Equipment

Rhode Island Legislative Act, Diesel Emission Reduction Act, 2010 – S2440 Sub A, Pages 1-9

2010 -- S 2440 SUBSTITUTE A AS AMENDED

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LC01494/SUB A
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S T A T E O F R H O D E I S L A N D
IN GENERAL ASSEMBLY

JANUARY SESSION, A.D. 2010

A N A C T
RELATING TO MOTOR AND OTHER VEHICLES -- THE DIESEL EMISSION REDUCTION ACT

Introduced By: Senators Miller, Sosnowski, Maher, Ruggerio, and Connors

Date Introduced: February 11, 2010

Referred To: Senate Environment & Agriculture

It is enacted by the General Assembly as follows:

SECTION 1. Chapter 31-47.3 of the General Laws entitled "The Diesel Emissions Reduction Act" is hereby amended by adding thereto the following sections:

31-47.3-1.1. Purpose. – This act shall be known and may be cited as "An Act Concerning Government Responsibility To Protect Public Health From Diesel Pollution." The general purposes of this act are to:

(1) Minimize human exposure to and health risks from diesel pollution;

(2) Reduce health costs, missed school days, lost worker productivity and premature mortality linked to exposure to the diesel particulate matter (PM) and other diesel pollutants;

(3) Achieve maximum feasible diesel particulate matter emissions reductions and diminished human exposure that is additional to the impact of federal diesel emission rules, which focus mostly on new engines;

(4) Advance the state's climate protection goals and climate action plan by reducing the amount of black carbon pollution emitted by diesels; and

(5) Achieve health benefits for Rhode Island by ensuring state contracting and leasing takes advantage of retrofits that are occurring in the marketplace.

31-47.3-4. Emission reduction strategies in new public works contracts. -- Effective upon passage of this legislation, any solicitation for a public works contract with the state, and any contract entered into as a result of such solicitation, shall include provisions requiring all heavy duty vehicles used in the performance of such contract to adhere to the following requirements:

(1) Contractors shall establish staging zones, provided that such space is available at no extra cost, for diesel vehicles away from the general public or sensitive receptors, including, but not limited to, hospitals, schools, and residential neighborhoods, to minimize the impact of emissions from idling vehicles.

(2) Idling of diesel engines shall be limited to no more than five (5) minutes, except in cases where the engine must idle to perform normal operations, as with a cement truck.

(3) Onroad and nonroad heavy-duty diesel vehicles, including generators, shall use only ultra-low sulfur diesel fuel.

31-47.3-5. Use of emission control technology in new public works contracts. – (a) Effective upon passage of this legislation, the department of transportation (DOT) shall implement contract requirements specified in subsection (b) on at least one project to be out to bid no later than September 30, 2010. Performance of the project, if deemed practicable by the director of DOT, must be started no later than six (6) months after the project bid has been awarded. DOT shall provide a summary report of the results of the project, implementation of these provisions and any recommendations to the governor and the general assembly no later than sixty (60) days after project completion. In selecting the project, the DOT shall prioritize otherwise eligible projects that:

(1) Each have a total individual budget of no less than six million dollars ($6,000,000);

(2) Serve areas in Rhode Island:

(i) With highest population density; and/or

(ii) Exposed to a disproportionate amount of air pollution from diesel fleets.

(b)Beginning January 1, 2013, any solicitation for a public works contract or contracts with the state funded in whole or in part by federal monies and having a total project cost of at least five million dollars ($5,000,000), and any contract entered into as a result of such solicitation, shall include provisions requiring all heavy duty vehicles used in the performance of such contract to adhere to the following requirements:

(1) Subject to the provisions of subdivisions (2) through (4), onroad and nonroad heavy-duty diesel vehicles, including generators, shall be powered by engines with properly operating and maintained Level 3 controls. Provided, however, that if the department of environmental management (DEM) finds that no Level 3 verified emission control devices have been verified and are otherwise appropriate for use on particular engines, Level 2 verified devices shall be required; if neither Level 3 nor Level 2 devices have been verified and are otherwise appropriate

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for use on particular engines, Level 1 verified devices shall be required; and

(2)The emission control technology requirements of subdivision (1) shall not apply to:

(i) Vehicles and equipment dedicated for snow removal;

(ii) Farm equipment;

(iii)Vehicles that are specially equipped and used for emergency response and vehicles that are used during a declared state of emergency and for the life of the project associated with the state of emergency;

(iv) Vehicles that are used to deliver equipment or material to and from the project site;

(v) Standby generators; and

(vi) Vehicles used on the project for less than thirty (30) total work days over the life of the project; and

(3) Unregulated, or pre-Tier 1 diesel engines are exempt from the requirements in subdivision (1). No later than December 1, 2011, DEM shall initiate a stakeholder process to determine how to reduce particulate emissions from unregulated, or pre-Tier 1 diesel engines, and how to create a statewide inventory of heavy duty diesel vehicles and how this inventory is published. The stakeholder process shall include representatives from industries that utilize pre-Tier 1 diesel engines. DEM shall report findings and recommendations from the stakeholder process to the governor and the general assembly no later than July 1, 2012; and

(4) Emission controls shall be required only to the extent of available reimbursement from project funds covering the equipment purchase and installation labor costs of the controls, provided that at least one percent (1%) of the total of each project budget shall be dedicated for such reimbursement.

(i) Funds shall be generally allocated to pay for the most cost-effective emission controls in terms of particulate pollution reduction per dollar spent.

(ii) Dedicated funds, subject to this subdivision (4), remaining after all eligible vehicles and equipment have been retrofit and reimbursement to contractors has been rendered subject to the provisions of this statute, may be considered part of the overall project budget as determined by the state.

(c) Implementation. The requirements of subsections (a) and (b) shall be implemented as specified by the state, and shall include the following:

(1) A blind bidding process;

(2) When project bids are awarded, the state shall notify the contractor in writing of the total budget for retrofits according to the provisions of subdivision (b)(4);

(3) Contractors must select vehicles and equipment to be retrofitted according to the

requirements of subsection (b) within the budget specified by the state. Contractors shall give priority to retrofitting vehicles and equipment that:

(i) Will likely spend the most time operating on the project;

(ii) Will disproportionately expose the surrounding community and sensitive receptors including, but not limited to, hospitals, schools and residential neighborhoods to diesel pollution; and

(iii) Are most cost-effective in terms of emission controls for particulate pollution reduction per dollar spent.

(4) Construction shall not proceed until the contractor submits an equipment list of all heavy-duty vehicles to be used on site, in the format specified by the department of environmental management, including the following:

(i) Contractor and subcontractor names and addresses, plus contact person responsible for the vehicles and or equipment; and

(ii) Documentation, including the technology type, EPA/CARB verification number/control Level, manufacturer, make, model, serial number of the retrofit device; the date the retrofit was installed; or in the case of a delayed shipment for retrofit parts and/or equipment, proof of purchase and the expected ship date from the manufacturer, for the retrofitted vehicles to be used on the project; and

(5) Equipment, as further defined in subdivisions (c)(3) and (4), not meeting the requirements of this section shall not be used on the project site; provided, however, that

(i) If the contractor can provide documentation demonstrating that a retrofit was ordered for noncompliant equipment, but not arrived yet, and that the failure to retrofit in a timely manner was caused by circumstances beyond the contractor's control, the noncompliant equipment may begin work on the project and operate on site for a maximum thirty (30) total work days or for additional time if authorized by the procuring agency.

(ii) If the contractor subsequently needs to bring on site equipment not on the equipment list specified in subdivision (4), the contractor shall submit written notification within forty-eight (48) hours to the procuring agency and the additional equipment shall be used on the project site for no more than thirty (30) total work days or for additional time if authorized by the procuring agency; provided that noncompliant equipment shall not be authorized for use more than three times during the life of the project.

(d) Reporting.

(1) The contractor shall submit monthly summary reports to the project manager, updating the equipment list, including diesel fuel use for the reporting time period for all

equipment used in the performance of the contract. The addition or deletion of any equipment shall be included in the summary and noted in the monthly report.

(2) By December 1, 2013, and December 1 of each subsequent year through 2015, the state shall submit contractors' monthly summary reports, along with all inventory lists and equipment lists to DEM in the form requested.

(3) By February 1, 2013, and February 1 of each subsequent year through 2015, DEM shall create and submit a summary report to the legislature. The report will be made accessible to the public by posting on the DEM website.

(4) The report submitted by February 1, 2013 shall include:

(i) A description of the state's implementation of the new contract requirements;

(ii) An estimate of the resulting diesel emission reductions;

(iii) An estimate of the total population of heavy-duty diesel vehicles and equipment in the state;

(iv) An estimate of the total population of retrofitted heavy-duty diesel vehicles and equipment in the state;

(v) A description of other appropriate measures of progress;

(vi) A description of problems encountered and opportunities for additional reductions in diesel emissions; and

(vii) Recommendations for any statutory changes including but not limited to:

(A) The appropriate emissions control technology for specific vehicle groups;

(B) The types of projects that shall require emissions controls;

(C) The appropriate funding mechanism for continued implementation of the program;

(D) The reporting requirements necessary to track and number heavy duty vehicles in use, and the number of retrofits that are achieved under the program, and

(E) The appropriate enforcing agent for the program.

(5) DEM shall provide written notice and opportunity for a public meeting and comment on the draft of the report due February 1, 2013.

(e) DEM, DOT and other state agencies may promulgate regulations regarding the solicitation, bidding and awarding of public works projects as defined in subdivisions 31-47.3-5(b)(1), (b)(2), (c)(4), and (d)(1) and regarding enforcement as defined in 31-47.3-6, provided that the scope of the rulemaking authority granted hereunder shall be narrowly construed. No rule promulgated hereunder shall expand the scope of or impose more stringent limitations than those expressly set forth in this act.

(f) Funding.

(1) All costs associated with the purchase and installation by a contractor of the emission control technologies for a specific project in order to comply with the contract provisions required by subsections (a) and (b) shall be fully reimbursed from project funds within sixty (60) days of the technology installation; provided that the compliant control technology is installed within thirty (30) work days after the applicable vehicle is brought onto the project site unless it meets the requirements provided in subdivision (c)(5).

(2) Retrofits installed with funds from the project shall remain on the heavy-duty diesel vehicle for the useful life of the emission control device or the vehicle or in the event the vehicle is sold out-of-state the retrofit technology may be removed at the contractor's expense and used on a piece of equipment that performs work within Rhode Island no later than one year from the date it was removed from the original equipment.

(g) Public education. Any project that is subject to public hearing requirements shall include at a minimum an overview of the diesel abatement strategies for the project as part of the public hearing presentation.

31-47.3-6. Enforcement. -- (a) Enforcement. The state shall include enforcement provisions in each contract subject to the provisions of section 31-47.3-4 and 31-47.3-5, which shall include, authorization for the state to conduct random inspections of contractor's equipment and records to ensure compliance provided that for the purpose of inspecting heavy duty vehicles and their records to determine compliance with these regulations, an agent or employee of DEM, upon presentation of proper credentials, shall have the right to enter any project location (with necessary safety clearances) where the designated vehicles are located or kept.

(b) After January 1, 2013 any person who fails to submit any information, report, or statement required by this regulation, or who knowingly submits any false statement or representation in any application, report, statement, or other document filed, maintained or used for the purposes of compliance with this regulation may be subject to administrative penalties. Administrative penalties shall be assessed by the department of environmental management in accordance with section 42-17.6. In assessing penalties, DEM will consider factors, including, but not limited to, the willfulness of the violation, the length of time of noncompliance, whether the fleet made an attempt to comply, and the magnitude of noncompliance.

31-47.3-7. Severability. -- If any clause, sentence, paragraph, section or part of this act shall be adjudged by any court of competent jurisdiction to be invalid and after exhaustion of all further judicial review, the judgment shall not affect, impair or invalidate the remainder thereof, but shall be confined in its operation to the clause, sentence, paragraph, section or part of this act directly involved in the controversy in which the judgment shall have been rendered.

SECTION 2. Sections 31-47.3-2 and 31-47.3-3 of the General Laws in Chapter 31-47.3 entitled "The Diesel Emissions Reduction Act" are hereby amended to read as follows:

31-47.3-2. Definitions. -- When used in this chapter:

(1) "Best available retrofit technology" means technology, verified by the United States Environmental Protection Agency or California Air Resources Board (CARB) for achieving reductions in particulate matter emissions at the highest classification level for diesel emission control strategies that is applicable to the particular engine and application. Such technology shall not result in a net increase in nitrogen oxides.

(2) "Heavy duty vehicle" or "vehicle" means any on-road or non-road vehicle powered by diesel fuel and having a gross vehicle weight of greater than fourteen thousand (14,000) pounds, or in the case of a nonroad vehicle, powered by diesel fuel and an engine with a rating of at least seventy-five (75) horsepower, including, but not limited to, non-stationary generators.

(3) "DEM" means the Rhode Island department of environmental management.

(4) "Director" means the director of DEM.

(5) "DOT" means the Rhode Island department of transportation.

(6) "Level 1 control" means a verified diesel emission control device that achieves a particulate matter (PM) reduction of twenty-five percent (25%) or more compared to uncontrolled engine emissions levels.

(7) "Level 2 control" means a verified diesel emission control device that achieves a particulate matter (PM) emission reduction of fifty percent (50%) or more compared to uncontrolled engine emission levels.

(8) "Level 3 control" means a verified diesel emission control device that achieves a particulate matter (PM) emission reduction of eighty-five percent (85%) or more compared to uncontrolled engine emission levels, or that reduces emissions to less than or equal to one one-hundredth (0.01) grams of (PM) per brake horsepower-hour. Level 3 control includes repowering or replacing the existing diesel engine with an engine meeting US EPA's 2007 Heavy-duty Highway Diesel Standards, published in the federal register at 66 Fed. Reg. 5001 (January 18, 2001), or in the case of a nonroad engine, an engine meeting the US EPA's Tier 4 Nonroad Diesel Standards, published in the federal register at 69 Fed. Reg. 38957 (June 19, 2004).

(9) "Closed crankcase ventilation system (CCV)" means a system that separates oil and other contaminant from the blow-by gases and routes the blow-by gases into a diesel engine's intake system downstream of air filter.

(10) "Full-sized school bus" means a school bus, as defined in (Rhode Island general law) section (31-1-3), which is a type 1 diesel school bus, including spare buses operated by or under contract to a school district, but not including emergency contingency vehicles or low usage vehicles.

(11) "Verified emissions control device" means a device that has been verified by the federal Environmental Protection Agency or the California Air Resources Board to reduce particulate matter emissions by a given amount.

(12) "Ultra low sulfur diesel fuel" means diesel fuel having sulfur content of fifteen parts per million (15ppm) of sulfur or less, as defined by the U.S. Environmental Protection Agency at 40 CFR section 80.520.

(13) “State agency” means each state board, commission, department, or officer, other than quasi-public corporations, the legislature or the courts, authorized by law to make rules or to determine contested cases.

(14) “Public works contract” means a contract with a state agency for a construction program or project involving the construction, demolition, restoration, rehabilitation, repair, renovation, or abatement of any building, structure, tunnel, excavation, roadway, park or bridge; a contract with a state agency regarding the preparation for any construction program or project involving the construction, demolition, restoration, rehabilitation, repair, renovation, or abatement of any building, structure, tunnel, excavation, roadway, park or bridge; or a contract with a state agency for any final work involved in the completion of any construction program or project involving the construction, demolition, restoration, rehabilitation, repair, renovation, or abatement of any building, structure, tunnel, excavation, roadway, park or bridge.

(15) “Contractor” means any person contracting directly or indirectly with the state to provide labor, services, materials and/or equipment for the performance of a public works contract. Contractor includes a prime contractor, subcontractor, and any contractor(s) hired by such subcontractor.

(16) “CMAQ” means the federal congestion mitigation and air quality improvement program, reauthorized by congress in 2005 by Sections 1101, 1103 and 1808 of the safe, accountable, flexible, efficient transportation equity act: a legacy for users (SAFETEA–LU) (Pub.L. 109–59, Aug. 10, 2005). SAFETEA-LU requires states and metropolitan planning organizations to give priority in distributing CMAQ funds for diesel engine retrofit projects, as well as other cost-effective emission reduction and congestion mitigation activities that benefit air quality.

(17) “DERA” means the federal diesel emission reduction act, enacted by congress as

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sections 791 through 797 of the energy policy Act of 2005 (Pub. L. 109–58, Aug. 8, 2005).

(18) "Fleet owner" means a person, business or the state that owns ten (10) or more heavy duty vehicles" operating in Rhode Island. Included in the total are related businesses owned and operated by a person, business or state.

(19) "Inventory list" means a list of all equipment owned, rented, or leased by a contractor.

(20) "Equipment list" means a list of all equipment owned, rented, or leased to be used on site.

(21) The "state" shall mean "state agencies or when related to "contractors" in this statute, the "state" shall mean the procuring agency or procuring agent.

31-47.3-3. Reducing emissions from school buses. – *(a) Purpose.* To reduce health risks from diesel particulate matter (DPM) to Rhode Island school children by significantly reducing tailpipe emissions from school buses, and preventing engine emissions from entering the passenger cabin of the buses.

(b) Requirements for Rhode Island school buses:

(i) By September 1, 2010, no full-size school bus with an engine model year 1993 or older may be used to transport school children in Rhode Island; and,

(ii) By September 1, 2010 any new bus added to current bus fleets or after September 1, 2010 whenever a new contract is entered into by a city, town, school district or the state all busses included in that contract shall be equipped with a closed crankcase ventilation system and either: (A) Shall be equipped with a Level 1, Level 2, or Level 3 device verified by the US Environmental Protection Agency or the California Air Resources Board; or (B) Shall be equipped with an engine of model year 2007 or newer; or (C) Shall achieve the same or higher diesel PM reductions through the use of alternative fuel such as compressed natural gas verified by CARB/EPA to reduce DPM emissions at a level equivalent to or higher than subparagraph (b)(ii)(B) above; and,

~~(ii)~~(iii) Providing there is sufficient federal or state monies, by September 1, ~~2010~~2012, all full-sized school buses transporting children in Rhode Island must be retrofitted with a closed crankcase ventilation system and either: (A) be equipped with a level 1, level 2, or level 3 device verified by the US Environmental Protection Agency or the California Air Resources Board; or (B) be equipped with an engine of model year 2007 or newer; or (C) achieve the same or higher diesel PM reductions through the use of an alternative fuel such as compressed natural gas verified by CARB/EPA to reduce DPM emissions at a level equivalent to or higher than ~~subsection~~ subparagraph (b)(iii)(B) above.

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Suggested Changes to Existing Legislation

Page	Section	Line	Text	Issue	Recommendation
1	37-47.3-1.1 subdivision (3)	9	"Achieve maximum feasible diesel particulate matter emissions reductions"	Maximum feasible reductions may be limited based on the criteria outlined in 31-47.3-5 subsection (b) subdivisions (1) through (3)	Insure that thorough and adequate testing procedures are adhered to for determining maximum feasible reductions.
2	31-47.3-4 subdivision (2)	7	"Idling of diesel engines shall be limited to no more than five (5) minutes"	Who is the enforcing authority?	Recommend referencing existing anti-idling legislation and establishing consistency with the enforcement mechanism in that separate legislation
3	31-47.3-5 subsection (b) subdivision (2vi)	10-11	"Vehicles used on the project for less than thirty (30) total work days over the life of the project"	This provision is intended to avoid undue cost to contractors who would otherwise have to buy new equipment and/or emissions control devices. However, it creates a loophole allowing contractors who own multiple types of the same equipment to swap machines out to perform the same tasks and avoid retrofitting the machines (e.g. rollers, dump trucks, backhoes). Additionally, there are some vehicles that will likely never be on site for more than a week (e.g. grader).	Recommend dropping time period to 15 days to limit the ease of swapping machines instead of retrofitting
3	31-47.3-5 subsection (b) subdivision (4)	21	"one percent (1%) of the total of each project budget"	Based on the RIDOT pilot program, which spent ~2.2% of the total project budget, this amount may be too small.	Recommend raising amount to at least 2%
4	31-47.3-5 subsection (c) subdivision (3ii)	4-5	"[Contractors must select vehicles and equipment to be retrofitted. Contractors shall give priority to retrofitting vehicles and equipment that:] Will disproportionately expose the surrounding community and sensitive receptors to diesel pollution".	This puts the onus of determining the "disproportionately" polluting equipment (through opacity testing or other means) on the Contractor.	Recommend insuring adequate funding for opacity testing of vehicles within budget line item allocated for retrofits, or making this the responsibility of another party in the retrofitting process (not the Contractor).

Page	Section	Line	Text	Issue	Recommendation
2-3, 7; 8	31-47.3-5 subsection (1); 31-47.3-2 subsections (1), (6), (7), and (8); 31-47.3-2 subdivision (11)	32-34; 1, 4-5, 16, 20, 23; 5	"EPA/CARB verification"; "a verified diesel emission control device"; "Verified emissions control device".	Some emission control devices have been EPA/CARB verified for off-road vehicles, but many have not. This requirement can rule out many viable emission control device options that are often less expensive while still achieving a comparable level of reduction. This can be counterproductive to what the legislation is trying to achieve.	Instead of requiring EPA/CARB verification of retrofit devices, consider using this as a starting point for retrofit selection. It is recommended that the manufacturer certification and warranty be evaluated and may be determined adequate, with verification potentially serving as additional insurance. This issue is discussed further in Chapter 2, in the section entitled "Retrofit Technology Verification Programs".
6	31-47.3-6 subsection (a)	17-21	"authorization for the state to conduct random inspections of contractor's equipment and records to ensure…compliance with these regulations, an agent or employee of DEM…shall have the right to enter any project location (with necessary safety clearances) where the designated vehicles are located or kept."	DEM does not have the capacity to enforce this provision.	Recommend that: either DEM be provided additional funding and staffing in order to meet these requirements, or that the contracting agency of each individual project, or state or local police should be able to enforce this within their respective jurisdictions.
7	31-47.3-2 subdivision (2)	12	"seventy-five (75) horsepower"	Under pilot project, 50 horsepower was the minimum threshold for mandating retrofits. EPA/CARB also use 50 horsepower as their threshold.	Recommend changing from 75 horsepower to 50 horsepower for consistency and increased emission reduction potential.
7	31-47.3-2 subdivision (6)	17	"twenty-five percent (25%)"	There are EPA verified devices that offer 20%. Most DOCs verified to reduce 25% and above require accompanying CCVs, which were found to not be applicable on most construction equipment.	Recommend changing from 25% to 20% for consistency with verified devices and manufacturer advertised reduction efficiency.
8	31-47.3-2 subdivision (15)	25	"Contractor includes a prime contractor, subcontractor"	RIDOT indicated that for this pilot project, subcontractor retrofits would not be paid for, but in the legislation subcontractors are included.	No change to the legislation is recommended. It is unlikely that a significant number of subcontractor vehicles would qualify to have retrofits installed and paid for under the terms of this legislation.

Appendix C – Verified Technologies Lists

EPA Verified Retrofit Technologies

<http://epa.gov/cleandiesel/verification/verif-list.htm>

The list below provides information on the emission reduction performance as verified by the EPA. By inclusion, EPA does not guarantee any performance or claims by the manufacturer, and the assigned reduction levels are only applicable when the technology is installed and used in accordance with the criteria described. EPA verification is not an evaluation of a product's safety or compliance with other regulatory requirements. Manufacturers, installers, fleets and operators must comply with all applicable local, state and federal safety regulations.

Manufacturer	Technology	Applicability	Reductions (%)			
			PM	NOx	HC	CO
BASF (formerly listed under Engelhard)	CMX Catalyst Muffler	Highway, heavy-duty, 4 cycle engines	20	n/a	50	40
Caterpillar, Inc.	Diesel Particulate Filter (DPF)	Nonroad, 4 cycle, non-EGR equipped, model year 1996-2005, turbocharged engines with power ratings 130 ≤ KiloWatts < 225 (174.2 ≤ Horsepower < 301.5)	89	n/a	93	90
Caterpillar, Inc.	Emissions Upgrade Group	Caterpillar model 3306 diesel engines for nonroad applications with model years from 1970 to 1995 with mechanical direct fuel injection.	22	37	71	13
Caterpillar, Inc.	Emissions Upgrade Group	Caterpillar model 3406 diesel engines for nonroad applications with model years from 1973 to 1995 with mechanical fuel injection.	Tier 1 Level (nonroad)			
Caterpillar, Inc.	Marine Engine Emissions Upgrade Group Kit #1 (MUI to EUI)	Caterpillar 3512 diesel engines for non-road, marine applications, model year 1994 – 2006 with mechanical direct fuel injection	35	35	18	60
Caterpillar, Inc.	Marine Engine Emissions Upgrade	Caterpillar 3508, 3512, and 3516 (large cam bore) diesel engines for	45	Tier 1 Level	28	65

Manufacturer	**Technology**	**Applicability**	**Reductions (%)**			
			PM	**NOx**	**HC**	**CO**
	Group Kit #2 (MUI to Tier 1)	non-road, marine applications, model year 1994 – 2006		(marine)		
Caterpillar, Inc.	Marine Engine Emissions Upgrade Group Kit #3 (MUI to Tier 2)	Caterpillar 3508, 3512, and 3516 (large cam bore) diesel engines for non-road, marine applications, model year 1994 – 2006	Tier 2 Level (marine)			
Clean Diesel Technologies, Inc. (CDTi) (Formerly Engine Control Systems Limited)	Purifilter EGR Diesel Particulate Filter (DPF)	Highway; light, medium, and heavy heavy-duty EGR engines, not originally certified or equipped with DPF, originally certified from 2002-2010 and listed in Attachment A enclosed with this letter.	90	n/a	90	85
Cummins Emission Solutions	Cummins Emission Solutions & Cummins Filtration Diesel Oxidation Catalyst (DOC) and Closed Crankcase Ventilation (CCV) System ETV	Highway, heavy-heavy and medium-heavy duty, 4 cycle, non-EGR, model year 1991 - 2003, turbocharged or naturally aspirated engines	30[2]	n/a	74	50
Donaldson	Series 6000 Diesel Oxidation Catalyst (DOC) & Spiracle Closed Crankcase Filtration system ETV	Highway, heavy heavy- and medium heavy-duty, 4-cycle, non-EGR, model year 1991 - 2003, turbocharged or naturally aspirated engines	25 to 33[2]	n/a	50 to 52	13 to 23
Donaldson	Series 6100 Diesel Oxidation Catalyst (DOC) ETV	Highway, heavy heavy- and medium heavy-duty, 4-cycle, non-EGR, model year 1991 - 2003, turbocharged or naturally aspirated engines	20 to 26	n/a	49 to 66	38 to 41
Donaldson	Series 6100 Diesel Oxidation Catalyst (DOC) & Spiracle Closed Crankcase	Highway, heavy heavy- and medium heavy-duty, 4-cycle, non-EGR, model year 1991 - 2003, turbocharged or	28 to 32[2]	n/a	42	31 to 34

Manufacturer	Technology	Applicability	Reductions (%)			
			PM	NOx	HC	CO
	Filtration system ETV	naturally aspirated engines				
Donaldson	Series 6400 Diesel Oxidation Catalyst (DOC) & Spiracle Closed Crankcase Filtration System	Highway, heavy-heavy and medium-heavy duty, 4 cycle, non-EGR, model year 1991 - 2003, turbocharged or naturally aspirated	28[2]	n/a	50	23
Engine Control Systems (ECS)	AZC Purimuffler or AZC Purifier Diesel Oxidation Catalyst (DOC)	Highway, heavy-duty, 4 cycle engines 1994 through 2006	20	n/a	50	40
Engine Control Systems (ECS)	AZM Purimuffler or AZM Purifier Diesel Oxidation Catalyst (DOC)	Highway, heavy-duty, 4 cycle engines 1991 through 2006	20	n/a	50	40
Engine Control Systems (ECS)	AZC Purimuffler or AZC Purifier Diesel Oxidation Catalyst (DOC) with ECS Closed Crankcase Ventilation (CCV) System	Highway, heavy-duty, mechanically or electronically injected, turbocharged or naturally aspirated, originally manufactured from 1994 through 2006 model years which meet a 5 or 4 g/bhp-hr NOx standard	25	n/a	50	40
Engine Control Systems (ECS)	AZM Purimuffler or AZM Purifier Diesel Oxidation Catalyst (DOC) with ECS Closed Crankcase Ventilation (CCV) System	Highway, heavy-duty, 4-cycle, mechanically or electronically injected, turbocharged or naturally aspirated, originally manufactured from 1991 through 2006 model years which meet a 5 or 4 g/bhp-hr NOx standard.	25	n/a	50	40
Engine Control Systems	Purifilter - Diesel Particulate Filter (DPF) ETV	Highway, heavy and medium heavy-duty; Urban Bus; 4-cycle; model years 1994 - 2003; turbocharged or naturally aspirated; non-EGR engines	90	n/a	85	75

Manufacturer	Technology	Applicability	Reductions (%)			
			PM	NOx	HC	CO
Engine Control Systems	Purifilter Plus - Diesel particulate filter (DPF) on the engine, electrical panel for active regeneration at the garage/maintenance yard	Highway; heavy, medium, and light heavy-duty; Urban Bus; 4-cycle; model years 1994 - 2006; turbocharged or naturally aspirated; non-EGR engines	90	n/a	85	75
Engine Control Systems	Purifilter Plus M - Diesel Particulate Filter (DPF) on the engine, electrical panel for active regeneration at the garage/maintenance yard	Highway; light, medium, and heavy heavy-duty EGR and non-EGR engines, not originally certified or equipped with DPF, originally manufactured from 1994-2010 and listed in Table A	90	n/a	30	75
Engine Control Systems	AZ Purimuffler or AZ Purifier Diesel Oxidation Catalyst (DOC) with Low Sulfur Diesel Fuel (LSD)	Highway, medium heavy-duty, 4-cycle, model years 1991 - 2003 Cummins and Navistar/International engines originally manufactured with no after treatment, turbocharged or naturally aspirated, non-EGR engines	40	n/a	70	40
Engine Control Systems	AZ Purimuffler or AZ Purifier Diesel Oxidation Catalyst (DOC) with ECS Closed Crankcase Ventilation (CCV) system with Low Sulfur Diesel Fuel (LSD)	Highway, heavy-duty, 4-cycle, mechanically or electronically injected, turbocharged or naturally aspirated, originally manufactured from 1991 through 2004 model years which meet a 5 or 4 g/bhp-hr NOx standard with open crankcase ventilation and no after treatment engines	40[2]	n/a	75	60
Engine Control Systems	AZ Purimuffler or AZ Purifier Diesel Oxidation Catalyst (DOC)	Highway, heavy heavy-duty, 4-cycle, model years 1991 - 1993 Cummins engines originally manufactured without exhaust after treatment,	35	n/a	70	40

Manufacturer	Technology	Applicability	Reductions (%)			
			PM	NOx	HC	CO
	with Low Sulfur Diesel Fuel (LSD)	turbocharged or naturally aspirated, non-EGR engines				
Engine Control Systems	AZ Purimuffler AZ Purifier	Highway, heavy duty, 2-cycle engines	20	n/a	50	40
Engine Control Systems	AZ Purimuffler AZ Purifier	Highway, heavy duty, 4-cycle engines	20	n/a	50	40
International Truck & Engine Corp.	Green Diesel Technology-Low NOx Calibration plus Diesel Oxidation Catalyst (DOC) with Ultra Low Sulfur Diesel (ULSD)	Highway, light heavy-duty, 4-cycle, Navistar/International engines, model years 1999 - 2003 in the following families: XNVXH0444ANA, YNVXH0444ANB, 1NVXH0444ANB, 2NVXH0444ANB, 3NVXH0444ANB	0 to 10	25	50	10 to 20
Johnson Matthey	Selective Catalytic Reduction Technology (SCCRT)	On-highway, 4-cycle, EGR and non-EGR, 250-500 hp heavy-duty diesel engines, originally manufactured from model years 1998 through 2006	90	70	90	85
Johnson Matthey	Selective Catalytic Reduction Technology (SCRT)	On-highway, 4-cycle, non-EGR, 250-500 hp heavy-duty diesel engines, originally manufactured from model years 1994 through 2002	90	70	95	90
Johnson Matthey	Advanced Catalyzed Continuously Regenerating Technology (AdvCCRT) System	Highway, 4-cycle; light-, medium-, and heavy- heavy duty diesel engines including turbo-charged or naturally aspirated, EGR and non-EGR, and originally manufactured from 2002 through 2006 model years	90	n/a	n/a	50
Johnson Matthey	Continuously Regenerating Technology[3] (CRT[3])	Highway, medium and heavy heavy-duty, 4-cycle, non-EGR, model year 1994 - 2006, turbocharged or	90	n/a	93	72

Manufacturer	Technology	Applicability	Reductions (%)			
			PM	NOx	HC	CO
	Particulate Filter	naturally aspirated engines				
Johnson Matthey	CEM™ Catalytic Exhaust Muffler and/or DCC™ Catalytic Converter	Highway, heavy- duty, non-urban bus, 4-cycle, non-EGR, model year 1988 – 1997 turbocharged or naturally aspirated diesel engines	20	n/a	50	40
Johnson Matthey	CEM™ Catalytic Exhaust Muffler and/or DCC™ Catalytic Converter	Highway, heavy- duty, non-urban bus, 4-cycle, non-EGR, model year 1998 – 2003 turbocharged or naturally aspirated diesel engines	25	n/a	50	40
Johnson Matthey	CEM™ Catalytic Exhaust Muffler and/or DCC™ Catalytic Converter	Highway, heavy- duty, non-urban bus, 4-cycle, EGR equipped model year 2003, EGR and non-EGR model year 2004 – 2006 turbocharged or naturally aspirated diesel engines certified without a diesel oxidation catalyst	20	n/a	50	40
Lubrizol	PuriNOx Water emulsion fuel	Highway & Nonroad, heavy-duty, 2 & 4-cycle	16 to 58	9 to 20	-30 to -120	-35 to 33
Nett Technologies, Inc.	BlueMAX 100	Nonroad, 4-cycle, non-EGR diesel engines between 75–370 kW power ranges, originally manufactured from 1996 through 2008 and originally certified without a catalyst to EPA Tier 1, 2, or 3 standards	0	65	90	85
Various	Biodiesel (1-100%)	Highway, heavy-duty, 2 & 4-cycle	0 to 47	-10 to 0	0 to 67	0 to 47
Various	Cetane Enhancers	Highway, heavy-duty, 4-cycle, non-EGR-equipped engines	n/a	0 to 5	n/a	n/a

Note: Reductions for after-treatment devices are based on installation of retrofit technologies on engines that were originally produced without diesel oxidation catalysts or diesel particulate filters.

CARB Currently Verified Technologies List

<http://www.arb.ca.gov/diesel/verdev/vt/cvt.htm>

This page last reviewed December 11, 2012

The following information is provided as a summary of verified diesel emission control strategies. Additional requirements specific to engine compatibility are provided in the Executive Order. The factors outlined in the Executive Order are legal requirements of each verification; therefore, these conditions must be met before determining if a particular device is applicable to the end-users type of engine. The Air Resources Board recommends that you contact the manufacturer, or their authorized distributor, prior to making any purchasing decision. Please click on the manufacturer link for additional information.

PM Level	Product Name	Technology Type	PM Reduction	NOx Reduction	Applicability
LEVEL 3	Boshart Engineering Econix DPF-A	DPF	85%	N/A	1993-2006 on-road; CARB diesel.
	Catalytic Exhaust Products Ltd. Dieselytic SXS-SC DPF	DPF	85%	N/A	Stationary prime and emergency standby generators and pumps with Tier 1, Tier 2, or Tier 3 certified off-road engines meeting 0.2 g/bhp-hr or less diesel PM
	Caterpillar DPF	DPF	85%	N/A	Specific 1996-2005 model years; off-road; CARB diesel; biodiesel.*
	Cleaire Allmetal	DPF	85%	N/A	1996- 2010 model year diesel engines in both tracked and rubber-tired off-road vehicles; CARB diesel; biodiesel.*
	Cleaire Horizon	DPF	85%	N/A	Most on-road diesel engines through 2006 model year; CARB diesel; biodiesel.*
	Cleaire Lonestar	Lean NOx Catalyst and DPF	85%	40%	Conditionally verified for 1996 through 2009 model year; rubber-tired off-road vehicles; CARB diesel; biodiesel.*
	Cleaire Longmile-S	DOC/DPF	85%	N/A	1993-2010 on-road; CARB diesel; biodiesel.*

	Cleaire Longview (reformulated)	Lean NOx Catalyst and DPF	85%	25%	1993-2006 model year on-road; CARB diesel; biodiesel.*
	Cleaire Phoenix	DPF	85%	N/A	Conditionally verified for 1996-2010 model year rubber-tired off-road vehicles. CARB diesel; biodiesel.*
	Cleaire Vista	DPF	85%	N/A	1993-2010 model year on-road; CARB diesel; biodiesel.*
	CleanAIR Systems PERMIT	DPF	85%	N/A	Stationary emergency and prime generators; CARB diesel; biodiesel.*
	DCL International Inc.	DPF	85%	N/A	1996-2011 model year, off-road; CARB diesel; biodiesel.*
	DCL International Inc. ROADWARRIOR.	DPF	85%	N/A	1994-2004 model year, on-road; CARB diesel; biodiesel.*
	DCL International Inc.	DPF	85%	N/A	Stationary prime and emergency standby generators, pumps, and compressors; Tier 1, 2, or 3 off-road engines certified to < 0.15 g/bhp-hr PM; CARB diesel; biodiesel.*
	Diesel Emission Technologies UltraTrap	DPF	85%	N/A	1994-2006 on-road; CARB diesel; biodiesel.*
	Dinex DiSiC	DPF	85%	N/A	Most trailer TRUs using 1999-2005 model year engines; CARB diesel.
	Donaldson LNF	DPF	85%	N/A	1993-2006 model year on-road; CARB diesel; biodiesel. CARB diesel; biodiesel.*
	Donaldson LXF	DPF	85%	N/A	2002-2006 model year on-road; CARB diesel; biodiesel.*

	Donaldson NR-LNF	DPF	85%	N/A	Conditionally verified for 1996 through 2010 model year off-road; CARB diesel; biodiesel.*
	Donaldson SEF	DPF	85%	N/A	1991-2006 model year on-road; CARB diesel; biodiesel.*
	Engine Control System Purifilter L (Low Load)	DPF	85%	N/A	1994-2004 on-road; CARB diesel; biodiesel.*
	Engine Control System Purifilter H (High Load)	DPF	85%	N/A	1993-2006 CA certified engines; Specific 1994-2006 Federally certified engines; on-road; CARB diesel; biodiesel.*
	Engine Control System Combifilter	DPF	85%	N/A	2007 or older off-road; CARB diesel; biodiesel.*
	Engine Control Systems Purifilter Plus	DPF	85%	N/A	1993 and 2010 on-road; CARB diesel; biodiesel.*
	Engine Control Systems Purifilter Plus M	DPF	85%	N/A	1993 - 2010 on-road; CARB diesel; biodiesel.*
	ESW Technologies ThermaCat	DPF	85%	N/A	1996-2010; off-road; 1993-2006 on-road; CARB diesel; biodiesel.*
	ESW Technologies ThermaCat™ e	DPF	85%	N/A	1994-2009; on-road; with EGR; CARB diesel; biodiesel.*
	Global Emissions Systems, Inc. (GESi) 6000DPF	DPF	85%	N/A	Stationary prime and emergency standby generators and pumps with Tier 1, Tier 2, or Tier 3 certified off-road engines meeting 0.2 g/bhp-hr or less diesel PM
	GTE Industries. Purity DPF	DPF	85%	N/A	Stationary prime and emergency standby generators and pumps with Tier 1, Tier 2, or Tier 3 certified off-road engines meeting

					0.2 g/bhp-hr or less diesel PM
	HUG Filtersystems Mobiclean R	DPF	85%	N/A	Most 1991 - 2006 on-road; CARB diesel; biodiesel. *
	HUSS Umwelttechnik FS-MK Off-Road	DPF	85%	N/A	Most off-road through 2011 MY; CARB diesel; biodiesel. *
	HUSS Umwelttechnik FS-MK On-Road	DPF	85%	N/A	Most on-road diesel engines through 2006 MY and most off-road through 2010 MY; CARB diesel; biodiesel. * Verified for 1998 and newer TRU's.
	HUSS Umwelttechnik FS-MK for TRU	DPF	85%	N/A	Verified for 1998 and newer TRU's. CARB diesel; biodiesel. *
	Impco Ecotrans CLEARSKY	DPF	85%	N/A	Select Kubota Z482 diesel engines with model years between 2005 and 2012: CARB diesel: biodiesel.*
	Johnson Matthey AdvCCRT	DPF	85%	N/A	Specifc 2002-2006; on-road; CARB diesel; biodiesel.*
	Johnson Matthey CRTreformulated	DPF	85%	N/A	1994 - 2006; on-road; CARB diesel; biodiesel.*
	Johnson Matthey CRT	DPF	85%	N/A.	Stationary emergency/standby generators; conditionally verified for stationary prime generators. CARB diesel; biodiesel.*
	Johnson Matthey EGRT	EGR/DPF	85%	40%	2000 International DT-466, 2000 Cummins ISM 2001 Cummins ISB, 1998-2002 Cummins ISC, 2001 Cummins ISL, 2001 MY DDC - 50, and 2001 DDC - 60. on-road; CARB diesel.
	MIRATECH Corporation	DPF	85%	N/A	Stationary emergency and prime generators with a PM emission

	combiKat				rate of 0.2 g/bhp-hr or less.
	Nett Technologies. NETT GreenTRAP™ DPF	DPF	85%	N/A	Stationary prime and emergency standby generators and pumps with Tier 1, Tier 2, or Tier 3 certified off-road engines meeting 0.2 g/bhp-hr or less diesel PM
	Proventia EHDPF	DPF	85%	N/A	Thermo King Tripac APU, powered by select model year 2007 to 2012 Yanmar TK270M diesel engines with a diesel particulate matter certification of 0.2 grams per kilowatt hour or less.
	RYPOS DPF/ULETRU	DPF	85%	N/A	2003 and newer Carrier and ThermoKing TRU's.
	Rypos, Inc. HDPF/C™	Hybrid DPF	85%	N/A	1996-2007 stationary emergency standby generators and pumps with a PM emission rate of 0.2 g/bhp-hr or less and certified to Tier 1, Tier 2, or Tier 3 off-road diesel engine standards; CARB diesel; biodiesel.*
	SK Energy Co. Econix DPF -A	DPF	85%	N/A	1994-2006; on-road; CARB diesel.
	Süd-Chemie Inc EnviCat-DPF™	DPF	85%	N/A	Stationary prime and emergency standby generators and pumps; CARB diesel; biodiesel.*
	Thermo King eDPF	DPF	85%	N/A	2006-2012 Thermo King auxilary power units; CARB diesel.
	Universal Emissions Technologies GreenShield® DPF	DPF	85%	N/A	Stationary prime and emergency standby power generators and pumps with Tier 1, Tier 2, or Tier 3 certified off-road engines.
	Engine Control	DOC + Alt	50%	20%	1996-2002 off-road; PuriNOx

LEVEL 2	System AZ Purimuffler/Purifier	Fuel			
	Lubrizol PuriNOx	Emulsified Fuel	50%	15%	1988-2003 on-road.
	Proventia FTF TM	FTF	50%	N/A	Most Thermo King trailer TRUs using 1985 through 2003 model year engines; CARB diesel; biodiesel.*
	Proventia Bobtail FTF ™	FTF	50%	N/A	Select Thermo King truck TRUs using 1987 to 2004 model year engines or Carrier Transicold truck TRUs using 1994 to 2004 model year engines. CARB diesel; biodiesel*
	Rypos ADPF	DPF	50%	N/A	1996-2008 stationary engines (certified to Tier 1, 2, or 3 off-road PM emission level); CARB diesel; biodiesel*; no EGR, DOC or pre-existing DPF.
	Rypos, Inc. DPF/LETRU™	DPF	50%	N/A	Applicability: Most trailer TRUs using 2003 and older model year engines; ULSD CARB diesel (less than 15 ppm sulfur).
	Rypos, Inc. ADPF	DPF	50%	N/A	Marine Harbor Craft
	Rypos ActiveDPF/C™	DPF	50%	N/A	Both diesel-electric and diesel-hydraulic rubber tired gantry (RTG) cranes; CARB diesel; biodiesel.*
LEVEL	Donaldson DCM 6000	DOC	25%	N/A	1988-1990 on-road; CARB diesel; biodiesel.*
	Donaldson 6000 + Spiracle	DOC + crankcase filter	25%	N/A	1988-2002 on-road; CARB diesel; biodiesel.*
	Donaldson 6000 +	DOC + crankcase	25%	N/A	Off-road port equipment; CARB

I	Spiracle (off-road)	filter			diesel; biodiesel.*
	Donaldson DCM 6100	DOC	25%	N/A	1994-2002; CARB diesel; biodiesel.*
	Donaldson DCM 6100 + Spiracle	DOC + crankcase filter	25%	N/A	1991-2002; CARB diesel; biodiesel.*
	Viscon California, LLC	Fuel Additive	25%	N/A	1985-1995 off-road; CARB diesel.
	Vycon REGEN System	Energy Storage System	25%	30%	Pre-1996 model year or Tier 1, 2, or 3 certified off-road diesel engines on rubber-tired gantry cranes; biodiesel. *

* These systems have been verified for use with biodiesel blends subject to certain requirements.

VERT

2. VERT® PFS - Approval Criteria

2.1. Curtailing particle emissions

- Filtration rate for solid particle number PCFE as defined by SN 277206 [10], must be attained in average of all operating points, throughout the particle size range 20-300 nm.

	A	B	C
From year	2000	2007	2013
New state	≥95%	≥97%	≥99%
2000 hrs.	≥90%	≥97%	≥99%

- During active regeneration, PCFE must be
  The criterion is the ratio of averaged values
- during the whole regeneration process
- Regeneration as specified by SN 277206
- Regeneration time < 3 % operation time
-

	1	2	3
From year	2010	2012	2013
New state	≥ 60%	≥ 70%	≥80%
2000 hrs.	≥ 60%	≥ 70%	≥80%

- During free acceleration reduction must be ≥ 95%
- The criterion is the ratio of the peak values
- Measurement as specified by SN 277206

2.2. Legislated emission limits

Compared to the baseline engine values, no increase of the limited emissions CO, HC, NOx and PM is permissible in the test cycle weighed average. During filter regeneration limited emissions shall not be higher than engine baseline emissions.

2.3. Secondary emissions

Secondary emissions are all compounds which were not present in significant concentrations in the exhaust gas of the base engine before retrofit. Formation of relevant amounts of such toxic reaction products is not permitted following [12,13].
Compared to baseline engine values, no relevant increase of the following toxic emission components is permissible in the treated exhaust gas after the PFS:

- Gaseous secondary emissions: principally NO_2, Dioxins and Furans, PAH and Nitro-PAH
- Aerosols of sulfuric acids
- Metal oxides (e.g. ash particles from additives, engine wear, lube oil additive packages)
- Mineral fiber emissions in the WHO defined size range L<3 µm; D<5 µm
- Limit Values for NO_2

Average NO_2 increase over engines baseline due to catalytic conversion of engine-out NO must not exceed 20 % in relation to NO upstream filter for all systems certified from 2013. This value shall be determined as per SN 277206 .

A	B
until year 2012	from year 2013
No limit	$\Delta NO_2/NO<20\%$

- Filter systems converting engine-out NO into NO_2 can only be used in environments where the concentration of NO_2 in ambient air is well below the locally valid air quality limits.

Relevance of other secondary emissions
Increase of trace substances like Dioxins, Furans, PAH, Nitro-PAH and metal oxide particles < 400 nm are deemed “relevant” when the exhaust gas after the PFS exhibits concentrations, exceeding thrice the engine emission without PFS, at the same operating points.

2.4. Pressure loss

- Fresh filter: < 50 mbar at high idle
- Regeneration threshold: < 150 mbar
- Maximum soot + ash burden: < 200 mbar (95% percentile)
- Alarm episodes > 5 sec above 200 mbar
- Special situations: If tolerated by the operator and the engine manufacturer, a pressure loss of maximum 300 mbar can be accepted at maximum soot+ash burden. Engines with uncontrolled EGR shall not be operated against more than 120 mbar back-pressure, the permissable level might be even lower and must be agreed by the engine manufacturer and the operator.

2.5. Additive dosage

Automatic with interrupt if filter ruptures. See VERT FBC-System specifications [7].

2.6. Function monitoring OBD (minimal requirements)

See VERT OBC-System specifications [8]

- Continuous electronic monitoring of backpressure and exhaust temperature
- Measurement every second, storage on 1 minute base
- Alarm signal and alarm logging when maximum back-pressure is exceeded.
- Additive (if used): dosage shut off when filter damage is detected.
- Special situations: For externally regenerated replacement PFS and temporary filters (so-called snap-on filters), the electronic monitoring can be substituted. Permitted is instead a simple pressure sensor with visual or acoustic alarm.
- In case the operator does not properly react to the alarms, the OBD-system shall activate an automatic safety feature

2.7. Noise Attenuation

Attenuation must be at least equivalent to the muffler replaced. For comparison near field measurement is specified [11].

2.8. Durability, Maintenance and Warranty

- Life expectancy > 5000 operation hours
- Usable hours until cleaning > 2000 operation hours
- Maintenance interval > 500 operation hours
- Guarantee on materials and function > 2 years or 1000 op. hours (whichever is earlier)

2.9. Labeling

Main and auxiliary components of the PFS must carry an identification plate in a manner that is durable, unambiguous and legible. This is necessary to determine the filter family clearly in a unique manner and must also contain at least the certification identity, serial number, manufacturing data for quality control and the flow direction. The information on this plate must be identical with the certification data in the VERT® filter list; especially the certification identity. In addition each vehicle retrofitted with VERT® approved PFS shall carry a green VERT® label with an individual running number to be identified for the VERT® data base.

2.10. Flow direction

Flow direction through the PFS must be indicated clearly with an arrow see 2.9. Moreover, unidirectional design must prevent reversed mounting of the filter element.

2.11. Safety

The PFS must be mounted according to the manufacturer's instructions such that no additional risks occur. The assembly must comply with the legislation on health, safety and visibility in the country where the PFS is deployed. Surface temperature requirements must be respected. Heat shielding is recommended and spark arrestors shall be used whenever the filter is operated under fire risk environmental conditions e.g. in forests or paper mills.

2.12. Bypass

Bypass arrangements, which permit circumventing the filter during excess back-pressure, are generally impermissible. Both manual and automatic bypass are prohibited.

2.13. Diagnosis access

Access to the mounted PFS is required to measure the raw emissions for engine diagnosis and to determine the filtration efficiency in situ if requested. For this purpose, the filter casing or exhaust pipe must have, upstream of the filter element, a diagnose access of minimum 40 mm inner diameter [11].

2.14. Cleaning and disposal

The filter element requires periodic cleaning from ash residues and the element must be eventually disposed off. Only methods that are environmentally acceptable, manufacturer approved and declared in the application documents for the suitability test shall be used for cleaning and disposal. The trapped residues are toxic wastes. These must be carefully collected and, if in small quantities, disposed together with other industrial waste in a garbage incinerator. The local authorities decide how larger quantities shall be disposed. Workers must be protected from exposure to fine dust during cleaning and disposal.

2.15. Substituting mufflers for PFS

Employing so-called muffler modules instead of PFS (e.g. during PFS maintenance or filter cleaning) is only permissible with the approval of the regulatory authorities. The only permitted muffler modules are those that are tested during the VERT® certification, described in the test reports and clearly identified as such.

2.16. Technical reporting the retrofit

An installation report must be prepared for each retrofit and signed by the retrofitter and the vehicle owner. See appendix VERT-acceptances test report and www.vsbm.ch. The retrofitted vehicle or equipment must display a VERT® Label with an individual running number, see Appendix. The installation report must be submitted to the VERT® coordination office for registration in the VERT® database.

2.17. COP = Conformity of Production

Responsibility of the manufacturers and subject to an annual VERT® audit procedure. The rules, for manufacturing quality control, are still to be defined.

2.18. IUC = In Use Compliance Tests

Responsibility of the manufacturers and subject to an annual VERT® audit procedure. The rules for periodic field testing of the PFS, are still to be defined.

2.19. Operation Manual

Each filter retrofitted must be accompanied by an operation manual in the language of the country where the filter is used. This manual must contain all information on functional, maintenance and safety issues, cleaning procedures and responsibility statements.

2.20. Impact on Energy Consumption

The overall energy impact of the PFS including all effects of back pressure and regeneration integrated over the life cycle must remain below 3 %.

2.21. Criteria for VERTdePN-Systems

- NOx - Reduction

	A	B	C
New state	≥85%	≥75%	≥65%
1000 hrs.	≥75%	≥65%	≥55%

- NH_3-emission < 25 ppm
- N_2O-emission < 10 ppm

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3. VERT® List of approved systems and components

3.1. Particle filter systems for prolonged deployment

	Suitability test				Status		Certificate	
MANUFACTURER PFS Type: PFS family F: Filter medium R1: Regeneration method 1 K: Electronic monitoring unit	VFT1	VFT2	VFT3	VSET	PCFE see 2.1	NO_2 see 2.3	Number	Date
AGD PFS Type: DIS F: CORNING DuraTrap® CO R: Cat. Corning = BASF DPX1 K: PDL.V3.3	B106/05.02	B196/12.06	B196/12.06	B114/03.03	C	A	B196/12.06	18.03.2010
AIRMEEX PFS Type: CARMEX SC F: IBIDEN SiC wallflow filter R1: FBC satacen (Fe) R2: FBC satacen 3 (Fe) K: AIRMEEX DTL 3600	B148/08.04	B171/11.05	B171/11.05	B043/09.97	C	B B	B171/11.05	18.03.2010
AIRMEEX PFS Type: CARMEX CSC F: CORNING DuraTrap® CO R: Catalytic Coating K: AIRMEEX DTL 3600	B206/09.07	B280/03.10	B280/03.10	B233/05.08	C	A	B280/03.10	22.07.2010
ARK/ASEC PFS Type: STARFILTER F: CTI SiC cell filter R: Catalytic Coating K: Dyntest	B225/06.08	B281/05.10	B281/05.10	B282/06.10	C	B	B281/05.10	22.07.2010
BASF PFS Type: DPX1 F: CORNING DuraTrap® CO R: Catalytic Coating K: Dyntest	B106/05.02	B123/02.03	B123/02.03	B114/04.03	C	A	B123/02.03	18.03.2010
BASF PFS Type: DPX2 F: CORNING DuraTrap® CO R: Catalytic Coating K: Dyntest	B106/05.02	B136/09.03	B136/09.03	B137/09.03	C	A	B136/09.03	18.03.2010

	Suitability test				Status		Certificate	
MANUFACTURER PFS Type: PFS family F: Filter medium R1: Regeneration method 1 K: Electronic monitoring unit	VFT1	VFT2	VFT3	VSET	PCFE see 2.1	NO_2 see 2.3	Number	Date
BAUMOT PFS Type: BAB/BA F: CORNING DuraTrap® CO R: Catalytic coating K: BauDAT AML	B210/12.07	B219/05.08	B219/05.08	B215/04.08	C	A	B219/05.08	18.03.2010
BERSY PFS Type: BPF-DOC F: Liqtech SiC cell filter R: CAM-FBC / satacen 3 K: Pirelli Ambiente	B165a/00.05	B199a/04.07	B199a/04.07	B179a/04.06	C	A	B199a/04.07	18.03.2010
BERSY PFS Type: BPF F: Liqtech SiC cell filter R: CAM-FBC (Fe) / satacen 3 K: Pirelli Ambiente	B165a/00.05	B200a/04.07	B200a/04.07	B179a/04.06	C	B	B200a/04.07	18.03.2010
DAUGBJERG A/S PFS-Type: SCAN-Filter F: Liqtech Sic cell filter R: FBC Pt Plus DFX (Ce, Pt) K: Daugbjerg PF-101-3000	B140a/12.03	B211/02.08	B211/02.08	B083/11.00	C	B	B211/02.08	10.10.2010
DCL PFS Type: MINE-X SOOTFILTER F: CORNING DuraTrap® CO R: Catalytic Coating K: DYNTEST AML V.3.0	B129/04.03	B230/08.08	B230/08.08	B231/07.08	C	A	B230/08.08	18.03.2010
DCL PFS Type: Titan™ and BlueSky™ F: IBIDEN SiC cell filter R1: Replace Filter R2: Electrical in-situ standstill R3: FBC satacen 3; EOLYS (Ce) K: DCL AF01	B078/07.00	B125/02.03	B125/02.03	B043/09.97	C	B B B	B125/02.03	18.03.2010
DINEX PFS Type: DIPEX (DPX1 and DPX2) F: CORNING DuraTrap® CO R1: Cat. Coating = BASF DPX1 R2: Cat.Coating. = BASF DPX2 K: DinLog, Dyntest	B106/05.02	B160/03.05	B160/03.05	B114/03.03	C	A A	B160/03.05	18.03.2010

	Suitability test				Status		Certificate	
MANUFACTURER PFS Type: PFS family F: Filter medium R1: Regeneration method 1 K: Electronic monitoring unit	VFT1	VFT2	VFT3	VSET	PCFE see 2.1	NO_2 see 2.3	Number	Date
DINEX PFS Type: DiSiC catalysed F: DINEX DiSiC cell filter R1: Cat. Coating = BASF DPX1 R2: Cat. Coating = BASF DPX2 K: DinLog, Dyntest	B220/05.08	B160/03.05	B269/09.09	B232/08.08	C	A A	B269/09.09	18.03.2010
EHC PFS.Type: EHC PF c.dpx coating F: LiqTech SiC cell filter R: Catalytic Coating K: CPK CDyntest	B235/09.08	B289/08.10	B289/08.10	B264/08.09	C	A	B289/08.10	10.10.2010
EMINOX PFS Type: DPF-CRT™ F: CORNING DuraTrap® CO R1: Catalytic Coating K: Eminox ESI	B112/10.02	B180/05.06	B180/05.06	B113/10.02	C	A	B180/05.06	180.3.2010
EMINOX PFS Type: DPF-FBC F: LiqTech SiC cell filter R1: FBC satacen 3 (Fe) K: Eminox REBE0156	B140/11.03	B167/10.05	B167/10.05	B043/09.97	C	B	B167/10.05	18.03.2010
EMINOX PFS Type: DPF-FBC Active F: LiqTech SiC cell filter R1: FBC satacen 3 (Fe) R2: on board electric K: Eminox REBE0156	B140/11.03	B244/12.08	B244/12.08	B043/09.97	C	B B	B244/12.08	18.03.2010
EXOCLEAN PFS Type: EXOCLEAN F: Ibiden SiC cell filter R1: Catalyst fuel combustion R2: FBC: EOLYS (Ce/Fe) K: SITA MOS	B147/07.04	B153/03.05	B153/03.05	B156/03.05	C	A B	B153/03.05	18.03.2010
HJS PFS Type: SMF®-AR F: HJS Sintermetall Filter R1: FBC HJS F51 (Fe) R2: FBC EOLYS (Ce) K: V1.43se; E13 039918	B155/04.05	B195/12.06	B195/12.06	B043/09.97	C	B B	B195/12.06	18.03.2010

	Suitability test				Status		Certificate	
MANUFACTURER PFS Type: PFS family F: Filter medium R1: Regeneration method 1 K: Electronic monitoring unit	VFT1	VFT2	VFT3	VSET	PCFE see 2.1	NO_2 see 2.3	Number	Date
HJS PFS Type: SMF®-FBC F: HJS Sintermetall Filter R1: FBC HJS F51 (Fe) R2: FBC EOLYS (Ce) K: V1.43se; E13 039918	B021/02.95	B049/5.98	B049/5.98	EMPA 167985	C	B B	B049/5.98	18.03.2010
HJS PFS Type: CRT® F: CORNING DuraTrap®CO R: Cat, Coating K: V1.43se; E13 039918	B053/4.98	B097/10.01	B097/10.01	B111/10.02	C	A	B097/10.01	18.03.2010
HJS PFS Type: SMF®-CRT® F: HJS-Sintermetall Filter) R: Catalytic Coating K: V1.43se; E13 039918	B155/03.05	B159/03.05	B159/03.05	B111/10.02	B	A	B159/03.05	18.03.2010
HUG PFS Type: mobiclean S (nauticlean; combikat) PF: HUG SiC cell filter R1: Cat.Coating (base metal) R2: Cat.Coating (precious metal) R3: Diesel burner K1 HUG integrated with burner K2 Dyntest AML	B216/06.08	R3:B168/08.05 R1,2:B227/07.08	R3: B168/08.05 R1,2: B227/07.08	R1:B157/04.04 R2:B229/07.08	C	B A B	R3: B168/08.05 R1,2: B227/07.08	18.03.2010
HUG PFS Type: mobiclean R PF: HUG SiC cell filter R1: Cat.Coating (base metal) R2: Cat.Coating (precious metal R3: Diesel burner K1: HUG integrated with burner K2 Dyntest AML	B216/06.08	R3:B168/08.05 R1,2:B228/07.08	R3: B168/08.05 R1,2: B228/07.08	R1:B157/04.04 R2:B229/07.08	C	B A B	R3: B168/08.05 R1,2: B228/07.08	18.03.2010
HUG PFS Type: mobiru F: Fiber woven filter system R: Diesel idle burner K: HUG integrated with burner	B099/11.01 only stationary application				A	B	B099/11.01	18.03.2010

	Suitability test				Status		Certificate	
MANUFACTURER PFS Type: PFS family F: Filter medium R1: Regeneration method 1 K: Electronic monitoring unit	VFT1	VFT2	VFT3	VSET	PCFE see 2.1	NO_2 see 2.3	Number	Date
HUSS-Umwelttechnik PFS Type: MA-Serie F: IBIDEN or CDC SiC R: FBC satacen 3 (Fe) K: HUSS integrated	B105/04.02	B203/05.07	B203/05.07	B043/09.97	C	B	B203/05.07	18.03.2010
HUSS-Umwelttechnik PFS Type: SK or W F: IBIDEN or CDC SiC R1: Electrical at standstill R2: Replace Filter K: HUSS ECU	B105/4.02	B105/4.02	B105/4.02	-------------	C	B B	B105/4.02	18.03.2010
HUSS-Umwelttechnik PFS Type: MK F: IBIDEN or CDC SiC R: Diesel burner at standstill K: HUSS integrated	B109/7.02	B131/4.03	B131/4.03	-------------	C	B	B131/4.03	18.03.2010
HUSS-Umwelttechnik PFS Type: ME F: IBIDEN or CDC SiC R: Electrical at standstill K: HUSS integrated	B105/04.02	B188/09.06	B188/09.06	-------------	C	B	B188/09.06	18.03.2010
HUSS-Umwelttechnik PFS Type: MD F: IBIDEN or CDC SiC R: Catalytic fuel combustion K: HUSS ECU	B212/02.08	B274/01.10	B274/01.10	B233/08.08	C	B	B274/01.10	18.03.2010
INTECO PFS Type: ECOPUR K xx yy F: Metal fiber fleece R: FBC satacen 3 K: INTECO	B082/10.00	B124/02.03	B124/02.03	B043/09.97	B	B	B124/02.03	18.03.2010
JOHNSON MATTHEY PFS-Type DPFi/DPFis/DPF-CRT™/ CCRT/CSF F: NGK Cordierit 200 cpsi R1: DOC / Cat. Coating R2 : Electric at Standstill R3: FBC satacen (Fe) R4: FBC EOLYS (Ce) K: PIO-CAN	B328/02.12	B090/04.01	B090/04.01	EMPA 167985	C	A B B B	B090/04.01-03.12	02.04.2012

	Suitability test				Status		Certificate	
MANUFACTURER PFS Type: PFS family F: Filter medium R1: Regeneration method 1 K: Electronic monitoring unit	VFT1	VFT2	VFT3	VSET	PCFE see 2.1	NO_2 see 2.3	Number	Date
LIEBHERR PFS Type: LIEBHERR F: CORNING DuraTrap® CO R: Cat. Coating = BASF K: integrated	B136/09.02	B192/11.06	B192/11.06	B137/09.03	C	A	B192/11.06	18.03.2010
LINDE-STILL-EBERSPAECHER PFS Type: ZSB F: NGK Cordierite R: Diesel burner at standstill K: integrated	B273/03.10	B275/03.10	B275/03.10	------------	B	B	B275/03.10	18.03.2010
PHYSITRON PFS Type: Physitec SiC-B; SiC-CB F: Ibiden-SiC; Liqtech SiC R1: Diesel burner at standstill R2: Catalytic Coating K: DNY / MultiControlBox	B132/04.03	B270/11.09	B270/11.09	B138/09.03	C	B B	B270/11.09	18.03.2010
PIRELLI PFS Type: FeelPure-DOC F: Pirelli & C.Eco Techn. R: CAM-FBC (Fe) K: Pirelli & C.Eco Techn.	B165/09.05	B199/04.07	B199/04.07	B179/04.06	C	A	B199/04.07	18.03.2010
PIRELLI PFS Type: FeelPure F: Pirelli & C.Eco Techn. R: CAM-FBC (Fe) K: Pirelli & C.Eco Techn.	B165/09.05	B200/04.07	B200/04.07	B179/04.06	C	B	B200/04.07	18.03.2010
PIRELLI PFS Type: FeelPure AR F: Pirelli & C.Eco Techn. R: CAM-FBC (Fe) K: Pirelli & C.Eco Techn.	B165/09.05	B279/03.10	B279/03.10	B179/04.06	C	B	B279/03.10	18.03.2010
PROVENTIA PFS Type: PROAIR DPFP FB F: Liqtech SiC cell filter R: FBC satacen 3 (Fe) K: Dyntest	B140a/12.03	B267/10.09	B267/10.09	B043/09.97	C	B	B267/10.09	18.03.2010

	Suitability test				Status		Certificate	
MANUFACTURER PFS Type: PFS family F: Filter medium R1: Regeneration method 1 K: Electronic monitoring unit	VFT1	VFT2	VFT3	VSET	PCFE see 2.1	NO_2 see 2.3	Number	Date
PURItech PFS Type: DAS-DBS F: NOTOX-SiC; LIQTEC-SiC R1: Catalytic combustion R2: FBC satacen 3 (Fe) K: PURItech Zentraleinheit	B224/06.08	B278/03.10	B278/03.10	B217/04.08	C	B B	B278/03.10	18.03.2010
PURItech PFS Type DPF-1/2; DPFN, DPFN+ F: Cordierite, 200 cpsi R1: Catalytic Coating K: PURItech Zentraleinheit	B314/09.11	B322/02.12	B322/02.12	B323/02.12	C	B	B322/02.12	01.03.2012
TEHAG PFS Type: CWF F: CORNING DuraTrap® CO R: Catalytic Coating K: Dyntest	B222/06.08	B254/02.09	B254/02.09	B246/12.08	C	B	B254/02.09	18.03.2010

3.2. On-board monitoring (OBM)

	Suitability test	Certificate	
MANUFACTURER Type	Number	Number	Date
CPK AUTOMOTIVE Electronic DPF Monitor & Control Dyntest V .4	B313/06.11	B313/06.11	30.6.2011
DEC De-Tronic	B327/01.12	B327/01.12	22.03.2012
MANN + HUMMEL ECU No. 1083898S01	B330/03.12	B330/03.12	20.03.2012

3.3. Particle filter systems for short duration usage

	Suitability test	Certificate	
MANUFACTURER Type F: Filter medium R: Regeneration method K: OBM electronic PFS monitoring	Number	Number	Date
ARPA-ER-ENDEAVOUR PFS Type: Progetto Blu F: Paper filter cartridge R: Disposal when>200 mbar K: ELIWELL TCJ - OV	B151/02.05	B151/02.05	18.03.2010
DT PFS Type. TWPF F: Ceramic / wire knit R1: Catalytic coating R2: Hot air blower, external K: Peak pressure manometer	B128a/07.04	B128a/07.04	18.03.2010

	Suitability test	Certificate	
EHC PFS Type: HT F: Micro Glass Fiber Media R: Incineration (ind.waste) K: Electric backpress. control	B135/10.03	B135/10.03	18.03.2010
EHC PFS Type: L20/P15 F: Micro Glass Fiber Media R: Incineration (ind.waste) K: Manual backpress. control	B272/03.00	B272/03.00	18.03.2010
HSE PFS Type: MF 180 / MF 100 F: Pleated Glass Fiber Media R: Incineration (ind. waste) K: Manual backpress. control	B277/03.10	B277/03.10	18.03.2010

3.4. Particle filter media

	Suitability test	Certificate	
MANUFACTURER F: Filter medium	VFT1	Number	Date
CDC-GmbH F: SiC cell filter, 200 cpsi	B212/02.08	B212/02.08	18.03.2010
CORNING F: CORNING DuraTrap® CO Cordierite cell filter. 100 cpsi	B066/02.00	B066/02.00	18.03.2010
CORNING F: CORNING DuraTrap® AC Cordierite cell filter, 200 cpsi	B314/09.11	B314/09.11	30.09.2011
DOW F: AERIFY DPF Mullite, 200 cpsi	B316/09.11	B316/09.11	30.09.2011
HUG F: HUG SiC cell filter	B216/04.08	B216/04.08	18.03.2010
IBIDEN F1: SiC cell filter F2: SiC cell filter	B062/10.99 B070/03.00	B062/10.99 B070/03.00	18.03.2010 18.03.2010
KHANCERA F: KDB200N SiC – 200 cpsi	B312/07.11	B312/07.11	30.09.2011
LIQTECH F1: SiC cell filter, 90 cpsi F2: SiC cell filter, 150 cpsi	B140a/12.03 B236/09.08	B140a/12.03 B236/09.08	18.03.2010 18.03.2010
NGK F: DHC-558 Cordierite, 200 cpsi	B328/02.12	B328/02.12	29.02.2012
SAINT-GOBAIN F: SG3-A1 SiC, 191 cpsi	B293/10.11	B293/10.11	22.11.2011

3.5. Regeneration additive (FBC)

	Suitability test	Certificate	
MANUFACTURER Name of the additive Active substance Maximum dosage	VSET	Number	Date
CDT Platinum Plus DFX-DPF Active substances Ce + Pt Dosage max. 7.5 mg Ce + 0.5 mg Pt/kg fuel	B083/10.00	B083/10.00	18.03.2010
INFINEUM Infineum F7990 and Infineum F7991 Active substance Fe Dosage max. 25 mg/kg fuel	B101/12.01	B101/12.01	18.03.2010
INFINEUM Infineum F7995 Active substance Fe Dosage max. 25 mg/kg fuel	B202/04.07	B202/04.07	18.03.2010
INNOSPEC satacen® Dosage max. 25 mg/kg fuel	B043/09.97 EMPA 167985	B043/09.97	18.03.2010
INNOSPEC HJS F51 Active substance Fe Dosage max. 36 mg Fe/kg fuel	B043/09.97 EMPA 167985	B043/09.97	18.03.2010
INNOSPEC Mann+Hummel DT 7 Active substance Fe Dosage max. 36 mg Fe/kg fuel	B043/09.97 EMPA 167985	B043/09.97	18.03.2010
PIRELLI CAM-FBC Active substance Fe Dosage max. 20 mg/kg fuel	B179/04.06	B179/04.06	18.03.2010

3.6. Particle filter systems with sales volume < 50 p.a.

	Suitability test	Certificate	
MANUFACTURER PFS Type: DeNOx-Type F: Filter substrate C: SCR-substrate R1: Regeneration method C1: DeNOx coating and Reductand K: Electronic on-board monitoring unit	VFT1 k	Number	Date

3.7. VERTdePN-Systems: Filtration + NOx-reduction

		Suitability test				Status			Certificate	
MANUFACTURER										
S: F: N: R1: C1: K:	DePN-Systrem or Type: Filter substrate DeNOx substrate Regeneration method 1 Conversion method Electronic monitoring unit	VPNT 1	VPNT 2	VPNT 3	VPNSET	K_{NOx} >75 / 65 / 55 %	NH_3 <20 / 30 / 40 ppm	N_2O <10 / 20 / 30 ppm	Number	Date
DINEX S: F: C: R1: C1: K:	 DiNOx-System DiSiC B269/09.09 HTAS Cordierite Catalytic Coating Vanadia + Adblue DinLog	B213/06.08	B329/03.12	B329/03.12	B259/06.09	A	A	A	B329/03.12	22.03.2012

4. Self commitments of VERT® certified Manufacturers & Retrofitters

A.Self-commitment of manufacturers of VERT® certified PFS:

- The PFS manufacturer commits to only sell VERT® certified PFS technology, which is identical with the certified state, as detailed described in his respective VERT® test reports.
- The PFS manufacturer commits to communicate all intended PFS alteration to the VERT® coordination office.
- The PFS manufacturer admits a VERT® Association officer to perform an annual quality audit.
- The PFS manufacturer controls the quality of his products in the field and submits complete information on failures annually to the VERT® coordination office.

B. Self-commitment of enterprises retrofitting VERT® certified PFS:

- Retrofitters must comply with the VERT® rules in this VERT® filter list
- Retrofitters must have a contractual relationship with the certified PFS manufacturer whereas.
  The PFS manufacturer is finally responsible for malfunction and liable for compensation also when the retrofitter is unable to settle the damage claims.
- Retrofitters must have their own workshop and trained employees to perform all necessary work for PFS installation, maintenance and repairs.
- Retrofitters must have officially calibrated measuring instruments for pressure and temperature control, particle emissions and noise emission,
- Retrofitters are capable of commissioning and of functional inspection of the PFS, compliant with all specifications and directives.
- Retrofitters shall enter into delivery contracts with their customers, promptly document all technical data, and grant their customers the VERT® specified guarantee for materials and function during at least 2 years.
- Retrofitters shall accept responsibility for damages consequent to PFS retrofitting. They are explicitly responsible for engine damage proven due to sustained back-pressure exceeding 200 mbar, provided the operator has done all necessary maintenance and did not ignore the alarms.
- Retrofitters shall document all retrofits on the one-page VERT® installation report, and send a copy of each such documents to the VERT® coordination office.
- Retrofitters shall affix the pertinent VERT® quality label with their company identification and a running VERT® control number on each retrofitted machines.
- Retrofitters shall report all failures to their PFS suppliers.
- Retrofitters shall participate once a year at VERT® filter technology fresh-up course and delegate all employees who are actually doing the retrofit job to such a course.
- Retrofitters and manufacturers shall clearly identify VERT® certified products in their leaflets, sales communication and exhibition documents using the worldwide protected trademarks VERT®, VERT-DPF®, VERT-certified®, whichever applies best.

Appendix D – Comparison of EPA, CARB, and VERT Verification Requirements

Table 1 *– reduced version with minor items deleted Comparison of the Verification Procedures* of –*

California Air Resources Board – Warranty and In-Use
Compliance Requirements for In-Use Strategies in Control of Emission from Diesel Engines

VERT Filter List. Tested and approved Particle-Filter Systems for retrofitting Diesel Engines

US EPA Voluntary Diesel Retrofit Program (VDRP,
Retrofit Technology Verification Process: OTAQ Verification Process and VDRP Verified Technology List

** reduced version with minor items deleted*

Verification Items	*California Diesel Risk Reduction – Verification Procedure*	*VERT Filter List – Suitability Tests*	*EPA Voluntary Retrofit Verification*
i. Application Process for Verification: Application Details	Details given in Section 2702 of CA Reg. Title 13. ECG engine name, make, model, model-year and PM / NOx cert. Examples of in-use vehicles or equipment, typical duty cycles, etc. EO review practical / scientific basis.	Application to. http://www.suva.ch Coordination by: TTM Technik Thermische Maschinen, Dipl.Ing A. Mayer –TTM.A.Mayer@bluewin.ch [Note 1]	QTAQ application – 3 paths. OTAQ/ETV Path = ETV manages. OTAQ Path = manufacturer manages. Path 3 = product update
ii. Published Verification List: [Note 2]	Website Note [3]. DECS Level 3 Verified Technology List regularly updated (check on regular basis)	Website Note [4]. Updated annually. Includes PFS ty4es, filter medium, regeneration method, and electronic filter monitoring for deployment. A separate filter class for brief deployment is listed	Website Note [5]. Verified Technology List updated periodically
iii. Emission Test Requirements:	**Section 2703**	**VERT Suitability Tests**	**RTI 5.0**
Baseline and Control Test Test Cycle:			
On-road: Engine cycle	FTP HD Transient, Title40,Part86,SubPartN (1 cold start; 3 hot start) NOx emission control technology may require additional testing	VERT qualifies PFS with VFT 1 – 4 modes of ISO 8178 100 / 60% engine speed; and 100 – 50% engine load tested in new condition, fully loaded with soot, during and after regeneration and at highest filter space velocity. All modes must pass	FTP 40 Part 86, Subpart N, 1 cold and 3 hot
Chassis cycle	FTP HD Transient,Title40, Part86,SubParttN as pertain to chassis + 3 hot-starts of UDDS CFR Title40, Part86, App I (d) plus 3 hot starts of low speed chassis cycle	Not used – engine test is sufficient	[Note 6]
Off-road: Engine cycle	CA C of Reg Title 13, Sect 2423 = CA Exhaust Emission Stds & Test Procedures for >2000 MY CI engines, Part 1 (B) (3 hot starts)	Same as On-road. All tests occur in VERT approved labs. VFT1 = new PFS test. Use ISO 8178 – average of 4 operating points including 1 at max permissible space velocity of the filter system and max T; VFT2 = PFS monitored prolonged deployment >2K op.hrs; VFT3 = PFS tests after VFT2, VFKT = test of electronic filter controls; VAST = test of additive system; VSET = VERT secondary emission test.	FTP 40 CFR Part 89, Subpart E. ETV Path 1 also Subpart D with 3 or more steady-modes to obtain 95% confidence. Allows for all-modes or selected modes of test
Monitor	Pressure + temperature and provide record	Mandated for all tests and deployed PFS. Minimum electronic log (3 months) backpressure and alarm signal functions are given. P max 200 mbar. Alarm 150 mbar. Max new 50 mbar. T found useful.	Not mentioned [Note 6]. Backpressure must be measured / reported during FTP at full load and rated speed
HC, CO and NOx analyses	Required. Additional analyses can be required depending on the technology	Required and compared to baseline – no emission increase permissible. Emissions also measured at high idle, low idle and converter stall for diagnostic purposes	Required

Verification Items	*California Diesel Risk Reduction – Verification Procedure*	*VERT Filter List – Suitability Tests*	*EPA Voluntary Retrofit Verification*
NO_2 analysis	Required	Required. No relevant increase (see 'relevant' in vi. Other Requirements)	[Note 6]
PM $_{(mass)}$ analysis	Required	Required – Elemental carbon mass per VDI 2465	Required
PM $_{(number)}$ analysis	Not Required	Required for particle count and elemental carbon mass concentration	Not required
Unregulated/Secondary Emission	EO can require if believed necessary	VSET (full ISO 8178 modes x 2) after VFT1 completed. Required for all catalytic systems. No relevant increase NO_2, dioxins, furans, PAH, nitro-PAH, sulfuric acid, additive ash particles or mineral fiber	Required as part of entire test data submission
Regeneration Tests	Emissions must be measured during regeneration event and taken into account for PM % reduction	VERT does not accept averaging. PFS must meet particle and elemental carbon criteria during each regeneration event	Repetitive cycles until regeneration = time weight average. Regeneration method described on issued ETV Verification Statement
iv. Durability Test Requirements:	**Section 2704**	**VFT2 Endurance**	**Durability RTI5.2.9**
Actual Field Tests	Extended service accumulation Option 1 is Actual Field Demo. 50K miles or 1K hours	Requires VFT2 prolonged 2000 hour endurance in monitored deployed application	Real-world operation for 33% of expected full-life. Table 3: 5y or 100K h, etc. MEDS BL and in-use tests. No MEDS specification given
Laboratory	Option 2 is Laboratory- based. 1K hours	VFT3 tests of PFS on laboratory engine after VFT2 2000 hour endurance	Accelerated bench testing simulating 33% of Table 2: 5y or 4200h. Filters or other can be removed from actual in-use vehicle and tested on lab engine
Fuel same for BL, control tests	Same fuel for all tests	All same fuel	[Note 6]
On-Road – x miles or x h service accumulation	50K miles, or 1K hours extended service or simulated lab aging	2000 hours in actual monitored deployment	Real world operation to 33% of 5 y or 150K miles HD, or 100K MD, or 60K MD or respective h
Off-Road – x h service accumulation	1K hours simulated lab aging (in-field or simulated lab aging is an option)	Same as on-road above	Engine aging to 33% of 5y or 4200 h for a > 50 hp
P, T data log – x miles or x h	Measured for 1000 hr or test duration. Also for 1 BL and each CNL test runs	Monitor and data log mandated for all tests and deployment of all PFS	T must be measured, RTI5.2.14
Electronic data log	Submit to EO	Mandated for all PFS tests and deployment	Not mentioned [Note 6]
3rd Party report	Required by EO approved 3rd party. Overall performance, maintenance, problems, visual and physical intact, secure mounting, leaks, observations	Not mentioned	Not mentioned
Test cycle type	Same as listed in Emission Test Requirements above for on-road and off-road	VFT3 is like VFT1 but modified	40 CFR Part 89, Subpart E for non-road. One or more full steady-state multimode FTP baseline and aged. Test method depends on retrofit product. BL and aged in-use tests have to be identical, rigorous, repeatable for tests to be directly comparable
Baseline/Control test emissions	B/L needed before start or at end – both recommended. Same set of control tests required before service accumulation, during and after completion – average result of each test series	Required	Required.
Before Start	Required	Required	Required
After	Required after 100% finished	Required after 2,000 hour durability test	After at least 33% of accumulated mileage or hours of minimum durability table for engine size
Maintenance	List of Scheduled Maintenance required – specify ash removal and disposal for DPF	Required - include maintenance interval/s and specify cleaning and disposal of ash residues. See also brief deployment PFS disposal	Required to be submitted with submission of test data

Verification Items	*California Diesel Risk Reduction – Verification Procedure*	*VERT Filter List – Suitability Tests*	*EPA Voluntary Retrofit Verification*
% Reduction Criteria	When aged to 100% of durability miles or hours must meet or exceed the verified % emission reduction level	PFS after 2 K op hrs must meet >95% reduction of 20-300 nm particle count and >90% EC mass. No change from new condition	New device aged to at least 33% of minimum durability miles or hours must meet verified % reduction level
Absolute Emission Criteria	Must be below 0.01 g/bhp-hr (applicable for Level 3 only)	No increase in legislated CO, HC, NOx and PM mass emission including during filter regeneration	Only % reduction
Physical Damage Criteria	Maintain physical integrity. Not cause engine damage, exceed backpressure, no maintenance beyond owner's manual	Safety – no additional risks. Assembly must comply to Swiss safety regulations	Not mentioned [Note 6]
Conditional Verification	EO can issue for off-road / stationary only. But! All durability requirements must be fulfilled 1 year	Verification only after passing all suitability tests	Not mentioned
Failure Criteria	EO may downgrade or deny verification	Must pass all suitability tests to be VERT listed. If >5% field failure = removal from list	Fail = removal from Verified Technology List
v. Field Demonstration of Compatibility:	Section 2705. Applicable when laboratory durability is chosen. In-field durability can satisfy this requirement		
Duration – x h or x miles	200 hours or 10,000 miles	California only	California only
3rd Party testament	Same as durability test		
Criteria: engine damage/malfunction	None		
Criteria: backpressure	Not exceed mfr limits **or cause damage to engine**		
Criteria: hindrance to engine, vehicle or equipment	None		
Criteria: physicals mounting, leakage, observable detectable damage	Robust		
Pressure and temperature data-logging requirements	Entire test period. Submit record to EO		
vi. Other Requirements:	Section 2706		
NO_2 level after catalyst technology. [Note 3]	NO_2 < than 30% over baseline engine NO_2 as of 1/1/07 and <than 20% over engine NOx as of 1/1/09 [CA ARB revision 3/23/06]	VSET - no relevant increase means less than permissible ambient air limits for workplaces; or OAPC limits; or shall not exceed thrice the without-filter at that operating point	Secondary emissions are mentioned - NO_2 limit not specified
HC, CO, NOx, PM emissions	Required – not exceed limits for each and also NH_3	Required – not exceed limits. VSET required.	Required. Must include secondary emissions. SOF of PM must be measured.
Fuel Borne Catalyst – require a DPF technology [CA ARB term is Fuel Additive]	Require DPF technology unless proven OK alone. On-board monitor alarm for low and empty FBC level. Also must shut off FBC feed if monitor detect DPF failure. Requires additional testing [2706 (c)]. Requires multimedia evaluation and EPA registration	Require a DPF. Monitor must detect DPF rupture with automatic interrupt of FBC dosing. Special specification listed in VERT Filter List	Not mentioned
Monitor and alarm for backpressure and temperature	Monitor P and T. Alarm required.	Mandated for all PFS tests and field deployments – found useful for warranty claims. Measure and record P (keep for 3 months). Alarm for high pressure [cleaning] and low pressure [filter rupture]	DPF inlet/outlet T and P during tests must be reported. Monitor not mentioned
Fuel and Lube Oil spec	Applicant specifies if different than Durability – see comment above.	Fuel EU500K <10-ppm S; Lube oil w/o S and low metal ash, TBN <30	Same as durability spec – see above
Schedule Maintenance List	Required	Required - emphasizes cleaning / disposal of ash residues	Required with submission of test data

Verification Items	*California Diesel Risk Reduction – Verification Procedure*	*VERT Filter List – Suitability Tests*	*EPA Voluntary Retrofit Verification*
Label	Required to have defined information and number assigned by EO	Label – durable, legible and unambiguous – identify filter family, serial no. and mfr data for QC, legible even after long deployment	Not mentioned [Note 6]
Owner's Manual	Specifies 10 types of information to be included	Not mentioned [Note 1]. Mentions education and information programs for users	Not mentioned [Note 6]
vii. Warranty Requirements:	Section 2707		Not mentioned
Noise Level Control	Same or lower as the original muffler	Equivalent of muffler replaced – close up measurement. Flow direction and diagnostic access (inlet and outlet exhaust sample tap)	Not mentioned [Note 6]
Warranty	Product warranty is required for full DECS repair or replacement and repair of engine damage, if any, caused by DECS; Installation warranty is covered in (a) (1); Owners warranty responsibility is defined separately. Applicant must submit a warranty report Feb 1 each year and within 30 days if claims exceed 4%	Required for product performance and installation where exhaust pressure <200 mbar. If exceeded can incur engine damage. Owner/operator responsible for maintenance and action upon monitor alarm indication. Retrofitter must submit an annual warranty report and immediately if failure exceeds 5%	[Note 6]
Warranty Periods: On-Road	See below:	PFS Life Expectancy >5K op.hrs; Usable hours to cleaning >2K op.hrs; Maintenance Interval >500 op.hrs; Guarantee for materials and function >2 y or 1K op.hrs for all PFS deployed	RTI report assumes same as Table 3 – California Minimum Durability Requirements for On-road and Off-road However, states that OTAQ will issue new Table (TBD)
Lt HD, 70-170hp, <19.5 K lbs	5 y or 60K miles		CA same or TBD
Med HD, 170-250hp, 19.5- 33K lbs	5 y or 100K miles		CA same or TBD
Hvy HD, >250hp, >33K lbs	5 y or 150K miles		CA same or TBD
Hvy HD, >250hp, >33K lbs and Driven over 100K m/y with less than 300K miles odometer at time of installation	2 y, unlimited miles		CA same or TBD
Warranty Periods: Off-Road		Same note as on-road	Same as on-road above
<25 hp and for constant speed engine under 50 hp with engine speeds > or equal to 3K rpm	3 y, or 1.600 hours		CA same or TBD
At or >25 hp <50 hp	4 y or 2,600 hours		Same as above
At or >50 hp	5 y or 4,200 hours		Same as above
viii. Determination of Emissions Reduction:	Section 2708		
Calculation Equations for % and Absolute reduction	Calculations and equations given	Particle count and EC mass are cited. Tests by SMPS, ELPI (13 stage type), NanoMet and other. Determined by VERT using approved engine labs	Calculated from BL and control technology test results
Emission Reduction Categories, if any	PM Level 3 => 85% PM reduction from BL or achieve absolute mass PM of <0.01 g/bhp-hr; Level 2 => 50%; Level 1 => 25% [Board may approve adding 'plus' levels at March 06 meeting]	One PFS category: > 95% Particle count and >90% EC mass concentration	No categories. PM levels calculated as PM mass % reduction. Example: 60% and 90%
ix. In-Use Compliance Testing:			
On-Road	Section 2709. Required	Manufacturer tests all deployed PFS biannually with smoke puff tests during engine free acceleration: pass equals less than 10% smoke (opacity <0.24m^{-1}; failure <3% = stay on list; >3%<5% = tests and correction; >5% = delist	Required

Verification Items	*California Diesel Risk Reduction – Verification Procedure*	*VERT Filter List – Suitability Tests*	*EPA Voluntary Retrofit Verification*
Off-Road	CA ARB will set off-road rules in 2006	Same	Required – none yet on Verified List as of 6/30/05
Minimum number units sold for start in-use Compliance Tests	50 (sold or leased)	N/A	500
Number of units to be tested	Min. 4, max 10 (for each phase)	Manufacturer field test all deployed PFS biannually and report results	Initially 4, maximum 10
Age criteria – to conduct Phase 1 testing	Conduct within 3 months after 1 year or Ist maintenance is reached	No Phases. Age or hours not specified	Phase 1: 25% of mileage or hours is reached
Age criteria – to conduct Phase 2 testing	Reach 60 to 80% min. warranty period	Same as above	Phase 2: reach 75% of mileage or hours
Pass / Fail criteria	+90% of verification level or <0.011 g/bhp-hr. If fail EO may lower verification level or delete from List	>5% failure of opacity K >0.24 m^{-1} value = remove from list. Manufacturer obliged to correct. <3% retained on list. >3% testing required	+ 75% of verification level – if fail remove from Verification List
4 of 4 pass	Pass	N/A	Pass
If one fails – new tests	+ 2 engines for each engine failed	N/A	Same as California
Final test criteria	70% of all engines tested meet >90% of verification level or <0.011 g/bhp-hr	>5% failure in one year = delete from list and manufacturer correction	70% of all engines tested must meet 75% of verification level
Report – timing, data	3 months after each phase – seven items covered	Must be reported annually to VERT – time not specified. Immediately if failures >5%	Test results in 3 months
Warranty claims	Claims report each year or when warranty claims exceed 4% (within 30 days)	VERT Listed Manufacturer must report to VERT each year	Not mentioned
Remedial report	If DECS family does not comply – remedial report with corrective measures in 90 days.	Not mentioned	Not mentioned
x. Manufacturers responsibility after verification:	a) Conducts in-use compliance test and provides results to EO. b) Submit annual warranty claims report to EO and when claims exceed 4% and submit in 30 days. c) If fails compliance tests submit remedial report to EO in 90 days	Obliged supply only technologies complying with VERT specifications that exactly fulfill the suitability tests. Promise advanced notice of intended changes; monitor the quality of their trap systems, and annual report to VERT on failure statistics of all PTS families on list.	a) Path 1 with ETV assistance. b) Path 2 Qualified manufacturers have complete application and test responsibility. c) Manufacturers use Path 3 for product upgrade or coverage revisions. d) Conduct and report in-use testing.
xi. Acceptance of other Verification Programs	ARB will review data from other programs and other preexisting data but will not blindly accept other programs' verifications. The ARB will work in conjunction with EPA to verify a technology. This applies to "hardware" only - fuel additives are not included. Accepts VERT Filter List but requires supplementary proof of filter compatibility with retrofitted engine types	None	Accepts CA Verified Process

[Note 1] All testing is conducted in approved laboratories with VERT coordination. It is assumed that test details not included in the VERT Filter List English Version are included in the German version in more detail or are covered in the VERT coordination activity

[Note 2] MSHA produces a DPM Technology List not reviewed here, http://www.msha.gov/01-995/Dieselpartmnm.htm. MSHA does not allow DOC for certain mines as it only removes organic soot and increases NO_2 and also limits DPF that produce NO_2

[Note 3] website for California Verification List, http://www.arb.ca.gov/diesel/verdev/level3/level3.htm

[Note 4] website for VERT Filter List; http://www.suva.ch, or http://www.umwelt-schweiz.ch/buwal/eng/fachgebiete/fg_luft/vorschriften/industrie_gewerbe/filter/index.html

[Note 5] website for US EPA OTAQ Verification List, http://www.epa.gov/otaq/retrofit/retroverifiedlist.htm

[Note 6] Each applicant has to submit a QA test plan RTI10.2. It is assumed that the test plan will include specifics on this other items will be included in the OTAQ approved test plan