Appendix B

Analysis of the Technical Feasibility and Costs of After-Treatment Controls on New Emergency Standby Engines

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TABLE OF CONTENTS

Contents **Page**

List of Tables **Page**

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I. ANALYSIS OF THE TECHNICAL FEASIBILITY AND COSTS OF AFTER-TREATMENT CONTROLS ON NEW EMERGENCY STANDBY ENGINES

In this appendix, ARB staff summarizes the results of an investigation into the technical feasibility, availability, costs, and operational considerations associated with DPFs and SCRs on emergency standby engines. ARB staff also provides an analysis of the estimated incremental costs associated with the transition from the Tier 2 or Tier 3 emission standards to Tier 4 standards for emergency standby engines.

A. Technical Feasibility and Operational Considerations for DPFs and SCR on Emergency Standby Applications

Diesel Particulate Filter Technology Description and Availability

DPFs are used in many applications to reduce emissions of diesel PM. In general, a DPF consists of a porous substrate that permits gases in the engine exhaust to pass through but collects or “traps” the diesel PM. Most DPFs employ some means to periodically remove the collected diesel PM. This is typically referred to as regenerating the DPF. During regeneration, the collected PM, which is mostly carbon, is burned off. Diesel PM emission reductions in excess of 85 percent are possible, depending on the associated engine's baseline emissions, fuel sulfur content, and emission test method or duty cycle. In addition, up to a 90 percent reduction in CO and a 95 percent reduction in HC can also be realized with DPFs. (ARB, 2003)

Particulate filters can employ active or passive systems. Active DPFs use a source of energy beyond the heat in the exhaust stream itself to help regeneration. Active DPF systems can be regenerated electrically, with fuel burners, with microwaves, or with the aid of additional fuel injection to increase exhaust gas temperature. Some active DPFs induce regeneration automatically onboard the vehicle or equipment when a specified engine back pressure is reached. Others simply indicate when to start the regeneration process. Some active systems collect and store diesel PM over the course of a full day or shift and are regenerated at the end of the day when the vehicle or equipment is no longer needed. Because they have greater control when regeneration occurs and are not as dependent on the engine exhaust temperatures, active DPFs have a much broader range of application and a much lower probability of getting plugged than passive DPFs.

A passive DPF is one in which a catalytic material, typically a platinum group metal, is applied to the substrate. The catalyst lowers the temperature at which trapped PM will oxidize to temperatures periodically reached in diesel exhaust. No additional source of energy is required for regeneration, hence the term "passive." Field experience has indicated that the success or failure of a passive DPF is primarily determined by the average exhaust temperature at the filter's inlet and the rate of PM generated by the engine. These two variables, however, are determined by a host of factors pertaining to both the details of the application and the state and type of engine being employed. As a result, the technical information that is readily accessible can sometimes serve as a guide, but it may be insufficient to determine whether a passive DPF will be successful in a given application. (ARB, 2003)

There are at least 13 manufacturers of DPFs for use in stationary emergency standby applications. As shown in Table B-1, ten manufacturers have DPFs that have been verified through the ARB's Diesel Emission Control Strategies Verification Program for use on emergency standby engines. There are three manufacturers that also provide DPFs for emergency standby applications; however their systems have not been verified by ARB.

Table B-1: Manufacturers of DPFs for Emergency Standby Applications

Company Name	DPF Type	ARB Verified
Catalytic Exhaust Products	Passive	Yes
CleanAir Systems	Passive	Yes
DCL International	Passive	Yes
GTE Industries	Passive	Yes
Johnson Mathey	Passive	Yes
Miratech	Passive	Yes
NETT Technologies	Passive	Yes
Rypos	Active	Yes
Sud-Chemie	Passive	Yes
Universal Emissions Technologies	Passive	Yes
Corning Environmental Technologies	Passive	No
Extengine	Active	No
Cleaire	Passive	No

DPF Operating Requirements

A DPF can collect PM for a set period of time before regeneration is required. The collection time will vary depending on the size, type, and manufacturer of the DPF but generally it ranges from 240 to 720 minutes (4-12 hours). Once this limit is reached the DPF system is designed to stop collecting PM and at this point, the filter should be regenerated. The manufacturer will stipulate the duration that the engine can operate between regeneration events. This is often specified as the number of cold starts and 30 minute idle sessions that the engine can perform before the DPF needs regeneration. Table B-2 below provides additional details pertaining to the manufacturer limits imposed on the passive DPFs for those systems verified through the ARB's Diesel Emission Control Strategies Verification Program. As shown in Table B-2, the number of cold starts that can be completed between regeneration events ranges from 10 to 30. Cold starts are commonly used to determine regeneration frequency because most emergency standby engine operation is associated with maintenance and testing operations, which generally entails short 15 to 30 minute engine operation at low or no loads. Regeneration requires exhaust temperatures ranging from 300 degrees celsius (℃) to 465 ℃ for 30 to 120 minutes depending on the DPF system.

Table B-2: Summary of Recommended Operating Requirements for Verified Passive DPFs

Parameters	General Operating Requirements
Minimum Exhaust Temperature for Filter Regeneration	300 ℃ to 465 ℃ for a duration of 30-120 minutes
Maximum Conservative Minutes Operating Below Passive Regeneration Required	240-720 Minutes
Number of Cold Starts & 30 Mins. Idle Sessions before Regeneration Required	10-30
Other Requirements	Engine cannot be equipped with exhaust gas recirculation

Operational Considerations for DPFs on Emergency Standby Engines

Typical operation of an emergency standby engine includes either weekly, biweekly, or monthly 30 minute maintenance and testing operations with low or no load to ensure the engine is operating properly.[1] As shown in Table B-2, the number of times that an engine can operate for maintenance and testing before regeneration can vary but typically is between 10 and 30 cold starts with 30 minute run sessions. For regeneration to occur, the exhaust temperature needs to be between 300 ℃ to 465 ℃. To reach this temperature and for a regeneration cycle to be completed, the engine should operate for about 30 minutes at a 30 percent load. This longer maintenance and testing session at a higher load would need to be performed when the filters require regeneration. In most cases, this would only be once or twice in a year.

Active DPFs are independent of temperature and will work on emergency standby engines without the same regeneration concerns noted above for the passive systems. The active DPF uses an electrical current or fuel combustion to remove or burn off the collected PM.

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[1] A survey conducted by ARB staff revealed that the average number of hours operated for maintenance and testing is about 22 hours, 7 hours for emergencies, and 2 hours for DRP operation per year. (ARB, 2003)

Emergency Standby Engines with DPF Applications

Actual in-use experiences with the application of DPFs on emergency standby engines were previously investigated when the ATCM was originally adopted. (ARB, 2003) At that time, ARB staff found that there were about 50 emergency standby engines operating in California that had DPFs installed. In most cases, the DPFs were installed to meet district permit requirements or to address odor complaints from near-by neighbors. Operators indicated that there was little or no additional maintenance associated with the DPF. To determine how this has changed since the initial staff report, staff asked the local air quality control and air quality management districts (districts) to provide data on emergency engines equipped with after-treatment devices. Eight districts provided this data which collectively reported 300 DPFs equipped emergency standby engines. (District, 2010)

ARB staff continue to believe that the application of DPFs on emergency standby engines is technically feasible and can achieve significant diesel PM emission reductions. The operational considerations are minimal and can be easily accommodated by small adjustments in the routine monitoring of the engines and normal maintenance and testing procedures.

SCR Technology Description and Availability

SCR technology has been available for many years, primarily used on large power plants to lower NOx emissions. However SCR is becoming more commonplace in other applications due to the U.S. EPA and ARB on and off-road new compression-ignition diesel engine standards.[2] For off-road applications, the Tier 4 final (Tier 4f) standards which are phased in between 2011 and 2015, most engines with horsepower (hp) greater than 75 hp will require highly effective NOx controls such as SCR.

SCR uses a catalyst (commonly precious metals, vanadium, or zeolites) and injection of a reductant (liquid ammonia or urea) to convert the NOx in the diesel exhaust to water (H_2O) and nitrogen (N_2). The catalyst lowers the reaction temperature that NOx needs to convert to H_2O and N_2. The temperature range is specific to each SCR system but in general it is between 260 ℃ to 540 ℃. Once the e xhaust temperature reaches the minimum operating temperature, the catalyst activates and the system begins to inject the reductant into the exhaust stream. The exhaust will then enter the catalyst where the conversion will take place. A well designed system can reduce the NOx emissions up to 95 percent.

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[2] U.S. EPA and ARB have adopted essentially the same emission standards for off-road engines. The ARB's Off-Road Compression Ignition Engine Standards (Off-Road Standards) can be found in title 13, CCR, section 2423. The U.S. EPA's Control of Emissions of Air Pollution from Nonroad Diesel Engines and Fuel, Final Rule June 29,2004 (Nonroad Standards) can be found at 40 CFR Parts 9,69, et. al. In both regulations, the diesel engine standards are phased in over several years and have Tiers, i.e. Tier 1, 2, 3 and 4; with increasing levels of stringency. The Tier 4 standards are broken into two subsets of emission standards, the Tier 4 interim (Tier 4i) and the Tier 4 final (Tier 4f). Generally, the Tier 4i standards require the application of DPF technology and the Tier 4f the application of both DPF and SCR technologies.

As shown in Table B-3, there are at least eight manufacturers who have indicated they have SCR systems for installation on stationary diesel engines. In most cases, these systems were designed for application on prime generators but can be adapted to work on emergency standby engines.

Table B-3: Manufacturers of Selective Catalytic Reduction Systems for Stationary Emergency Standby Engine Applications

CRI Catalyst
Ducon Technologies, Inc.
Epcon Industrial Services, LP
Foster Wheeler Energy Corp.
Johnson Matthey
Miratech Corporation
NETT Technologies
Universal Emissions Technologies

SCR Operating Requirements

As discussed earlier, SCR systems have two key operating variables that work together to achieve the NOx reductions. These are the exhaust temperature and the injection of the reductant (urea or ammonia). With respect to the exhaust temperature, the exhaust temperature must be between 260 °C to 540 °C for the catalyst to operate properly. For this reason, SCR systems will not begin injection of urea or ammonia until the catalyst has reached the minimum operating temperature. During this warm-up period, the engine can operate but without the benefits of the NOx reductions from the SCR system. The urea or ammonia injection is also a critical component in determining the control efficiency of a SCR. It must be injected into the exhaust stream upstream of the SCR system. In the catalyst, it reacts to reduce the NOx to form N_2 and H_2O. The reaction is able to take place because the catalyst lowers the reaction temperature necessary for NOx.

Operational Considerations for SCR Systems on Emergency Standby Engines

As mentioned above, SCR systems require an operating temperature between 260 °C to 540 °C. Reaching these temperatures may be difficult in routine maintenance and testing operations where the engine is typically operated at low load for short periods of testing. If this temperature is not met while the engine is running, there will not be any NOx emission reduction benefits. To circumvent this problem, the engine would need to be operated with higher loads and in many cases for longer periods of time. This could be a challenge for most emergency standby applications as most businesses do not have load banks in house and would have to create a larger load on the engine to get the catalyst up to operational temperature.

Urea handling and maintenance is also an important consideration. Urea crystallization in the lines can cause damage to the SCR system and to the engine itself. Crystallization in the lines is more likely in emergency standby engines due to their periodic and low hours of usage. Urea also has a shelf life of approximately two years. This could increase the cost of operating a SCR for emergency standby engines since the low number of annual hours of operation experienced by most emergency standby engines could lead to urea expiration. The urea would then have to be drained and replaced, creating an extra maintenance step and an increased cost to the end user.

Emergency Standby Engines with SCR Applications

There are a limited number of examples to draw upon for SCR installations in California. There are 7 facilities with SCR systems on 17 engines in California based on district permit data from eight districts. (District, 2010) These SCR systems were installed to comply with local district rules and regulations. ARB staff contacted operators of two facilities, one in California and one in Delaware, to obtain information on actual in-use experience with SCR systems on emergency standby engines. Brief summaries of what was reported are provided below.

Raging Wire: Raging Wire located in Sacramento, California, provides electronic data storage for businesses. They have equipped two of their diesel generators with SCR to meet the district's best available control technology (BACT) requirements for NOx. The SCR systems are installed on two Tier 1 two megawatt diesel engines and according to the district permit, are designed to reduce NOx between 35 and 60 percent. The two SCR systems are manufactured by Johnson Matthey. A Raging Wire representative provided ARB with their maintenance and testing records from the past two years. On average they operate about 20 hours per year for maintenance and testing procedures and 3 hours per year for emergency operation. It was indicated that a representative from Johnson Matthey must come out and service the SCR system twice a year to insure proper operation of the system.

Verisign, Inc.: ARB staff contacted representatives with Verisign, Inc. in New Castle, Delaware to discuss their experiences with SCR systems installed on six Caterpillar 3516 emergency standby diesel engines. Verisign, Inc. is a data and internet protection business. The engines have had an SCR system installed for approximately one year. The operator was very impressed with the system and was pleased with the results that he was seeing. For their SCR systems, the catalyst must reach 260 ℃ (500℉) to start to operate. When the engine is used at full load (2.2 MW) the SCR system begins to operate in approximately 10 minutes. Urea usage is 7-9 gallons per hour at full load. At very low load, the SCR system will not begin to operate for 30-40 minutes. It was their experience that occasionally the SCR system will not operate during an emergency because the loads are too low and the desired temperature is not reached. One major concern that they found with low use was that the urea had crystallized in the lines and leaked on multiple occasions.

SCR systems have not yet seen wide application on emergency standby engines and SCR systems currently in-use are on large emergency standby diesel engines greater than 1,000 horsepower. ARB staff believes that while the current generation of SCR systems may be technically feasible, there are significant operational hurdles to overcome before routine use of SCR on emergency standby engines is practical. This is because the majority of operating hours for emergency standby engines occur during short 15 to 30 minute maintenance and testing checks are at low engine loads. In most cases, the temperature needed for the SCR catalyst to function will not be reached during this operation and the SCR will not provide the expected NOx reductions.

B. Incremental Costs Associated with DPF and SCR on Emergency Standby Engines

To determine the potential costs associated with the application of DPF and SCR technologies on emergency standby engines, ARB staff investigated the costs associated with five different “compliance pathways” or scenarios that resulted in the application of DPFs and/or SCRs on emergency standby generator engines (gen-set). Two scenarios were based on the end user retrofitting an existing Tier 2 or Tier 3 engines with after-treatment technologies and three scenarios were based on original equipment manufacturers (OEM) providing the engine with after treatment technology installed. The five scenarios are:

Scenario 1) end user aftermarket retrofit of a Tier 2 or Tier 3 gen-set with a DPF;
Scenario 2) end user aftermarket retrofit of a Tier 2 or Tier 3 gen-set with a DPF and SCR;
Scenario 3) OEM supplied new Tier 4 interim (Tier 4i) gen-set (DPF only);
Scenario 4) OEM supplied new Tier 2 or Tier 3 gen-set retrofitted with OEM supplied DPF; and,
Scenario 5) OEM supplied new Tier 4 final gen-set (with DPF and SCR).

<u>Approach for Estimating Costs</u>

In each case, to determine the cost increase, we compared the cost of a new Tier 2 or Tier 3 gen-set with the cost of a gen-set equipped with after-treatment controls via the compliance path specified for each scenario. ARB staff aggregated engines into five horsepower ranges: 50-174, 175-749, 750-1,206, 1,207-2,000, and greater than 2,000. Estimated costs for end-user retrofit were based on data from after-market technology providers and OEM costs were provided by EMA members. For each specified horsepower range, the percent increase in cost for a gen-set with after-treatment compared to a new Tier 2 or Tier 3 gen-set without after-treatment was determined for the average size horsepower engine within each horsepower range.

To collect information on the costs for a new Tier 2 or Tier 3 gen-set and the costs associated with gen-sets that would meet each scenario that relied on OEM supplied engines, ARB staff worked with EMA to survey the OEMs. The survey asked for the current average costs for a Tier 2 or Tier 3 gen-set which are currently being sold. ARB asked manufacturers to estimate the future cost as a percent increase over a Tier 2 or Tier 3 gen-set of an OEM supplied DPF on a Tier 2 or Tier 3 engine, a Tier 4i engine (with DPF), and a Tier 4 gen-set (with DPF & SCR). The cost was the total cost to the end user without the cost of installation. This survey was sent to EMA to distribute to its members. ARB received responses from four manufacturers: Caterpillar, Inc., Cummins, Inc., Cummins West, and MTU Detroit Diesel.[3] To protect the confidentiality of the data provided by each OEM, the data provided was combined and the average used for the cost estimates and presented in this appendix. The estimated costs were the cost for emergency standby gen-sets only and included any costs the OEMs would incur for research, design, assembly line setups, after-treatment technologies, tooling, inventory storage, engine markup, and other considerations. It is important to note that, while EMA members provided estimates of their costs to produce the OEM supplied engines, they also stated that it is not economically viable for them to maintain a California-only platform for these engines and that these engines will not be available "off-the-shelf" from the OEMs.

For the end-user DPF retrofit scenarios, ARB staff relied on DPF retrofit cost data collected during the development of the ATCM. At that time, as outlined in the staff report developed in support of the ATCM, the estimated cost to retrofit a stationary diesel engine with a DPF was $38 per hp which includes capital and installation costs. (ARB, 2003) ARB staff conducted additional outreach to current DPF vendors to verify that this cost estimate is still applicable. ARB staff contacted manufactures of DPFs currently verified through ARB's verification procedure and found that the cost ranges from $25 to $55 for both active and passive systems with an average cost of $39 per horsepower.[4] Based on this, ARB staff believes the estimate of $38 per horsepower is still a reasonable cost estimate for a DPF retrofit. To determine the retrofit costs for a SCR system, staff contacted four SCR manufacturers and solicited SCR cost data. Based on the responses received, the capital costs for SCR systems ranged from $50 to $150 with an average cost of $80 per hp. This does not include the cost of installation which, according to the SCR manufacturers, could increase costs by 25 percent to over 100 percent. (Miratech, 2010)

The various cost assumptions and considerations for the different scenarios are summarized below.

Scenario 1: End User Aftermarket Retrofit of a Tier 2 or Tier 3 Gen-Set with a DPF

In this scenario, it is assumed that the end user purchases an "off-the-shelf Tier 2 or Tier 3 gen-set that meets a 0.15 g/bhp-hr PM standard and installs a DPF purchased from an aftermarket supplier. As discussed above, the estimated costs to retrofit an gen-set with an aftermarket DPF were $38 per hp. This estimate reflects the costs to

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[3] Clarke also provided cost information; however, it was excluded due to the fact that they provide direct drive fire pumps instead of generator sets. The data would not be compatible.

[4] Miratech, Johnson Matthey, and Rypos provided estimated costs for DPFs for multiple horsepower ranges. The estimated costs were aggregated to protect confidentiality.

purchase the DPF and install it on the gen-set. As shown in Table B-4, the estimated percent cost increase for this scenario relative the costs for a new Tier 2 or Tier 3 gen-set without after-treatment is between 15 percent and 26 percent.

Scenario 2: End User Aftermarket Retrofit of a Tier 2 or Tier 3 Gen-Set with a DPF and SCR

This scenario assumes the end user purchases an ‘off-the-shelf” Tier 2 or Tier 3 gen-set that meets a 0.15 g/bhp-hr PM standard and installs both a DPF and a SCR. ARB staff relied on the estimated costs of $38 per hp noted previously to retrofit an gen-set with a DPF and added to that cost, the cost to also retrofit with a SCR. As discussed above, the SCR retrofit costs were estimated to be $80 per horsepower. This estimate included only the capital cost because the manufacturers indicated that the installation costs are site-specific exercise and it is difficult to estimate an average cost. As shown in Table B-4, the estimated percent cost increase for this scenario relative the costs for a new Tier 2 or Tier 3 gen-set without after-treatment is between 46 percent and 82 percent.

Scenario 3: OEM Supplied New Tier 4 Interim Gen-Set

Under this scenario, it is assumed that the OEMs will develop and maintain a Tier 4i platform for emergency standby gen-sets. The Tier 4i standards, for most horsepower ranges, require a DPF to meet stringent PM limits and additional engine modifications to meet lower NOx limits. To meet the lower NOx limits, engine manufacturers indicated that exhaust gas recirculation (EGR) would be required; SCR would probably be required for gen-sets greater than 1207 hp. For this scenario, ARB staff relied on the OEM data provided on the estimated percent increase in costs relative to a new Tier 2 or Tier 3 gen-set without aftermarket controls. These estimates are provided in Table B-5 below and range from 55 percent to 105 percent. As noted above, the final OEM costs reflected the cost to the end user and included research, design, assembly line setups, tooling, inventory storage, engine markup, add-on control devices, and other considerations.

Scenario 4: OEM Supplied New Tier 2 or Tier 3 Gen-Set with DPF

In this scenario, we assumed that the OEM would provide a Tier 2 or Tier 3 gen-set with OEM supplied DPF after-treatment. As shown in Table B-5, the estimated percent cost increase for this scenario relative the costs for a new Tier 2 or Tier 3 gen-set without after-treatment is between 30 percent and 65 percent, about double the costs of those in Scenario 1 where the end user would retrofit a DPF to an existing gen-set.

Scenario 5: OEM Supplied New Tier 4 Gen-Set (with DPF and SCR)

This scenario assumes that the OEMs would develop and maintain a Tier 4f emergency standby diesel gen-set platform for the California market. The costs for this scenario were based on the data provided by the OEMS. As shown in Table B-5, the estimated percent cost increase for this scenario relative the costs for a new Tier 2 or Tier 3 gen-set without after-treatment is between 65 percent and 125 percent.

Estimated Increase in Gen-Set Costs for the Five Scenarios

Table B-4 provides a summary of the estimated cost increase associated with the Scenarios 1 and 2 that entailed the end user retrofitting a new Tier 2 or Tier 3 gen-set with a DPF or with both a DPF and SCR. For each scenario, the costs are presented as a percentage increase and as the increase in actual dollar amount, relative to a new Tier 2 or Tier 3 gen-set. As can be seen in Table B-4, the costs for an end user to retrofit an emergency standby gen-set with a DPF range from $4,000 to $100,000 per gen-set depending on the horsepower. The cost for an end user retrofit with DPF and SCR ranges from $13,000 to $310,000 per gen-sets.

Table B-4: End-User Retrofit Scenarios: Cost Increases for Emergency Standby Generator Sets

HP Range	Cost of NewTier 2/3 Gen-Set ($)	Aftermarket DPF Regulatory Scenario		Aftermarket SCR + DPF Regulatory Scenario	
		% Increase	$ Increase	% Increase	$ Increase
50-174	$29,000	15%	$4,000	46%	$13,000
175-749	$67,000	26%	$18,000	81%	$55,000
750-1206	$141,000	26%	$37,000	82%	$115,000
1207-2000	$309,000	20%	$61,000	61%	$189,000
>2000	$523,000	19%	$100,000	59%	$310,000

The cost increases associated with Scenarios 3, 4, and 5 that relied on OEM provided after-treatment based engines and technologies are provided in Table II-2. The OEM costs for Tier 4i and Tier 4f gen-sets reflect the addition of DPF and/or SCR after-treatment devices and any costs the OEMs would incur for research, design, assembly line setups, tooling, inventory storage, engine markup, and other considerations. For Tier 4i, a DPF will be required to meet the PM standards on all engines greater than 75 hp. For engines greater than 1207 hp, SCR systems will also likely be required to meet the Tier 4i NOx standard. For the Tier 4f engines, both DPF and SCR systems will be required on all engines greater than 75 hp

Table B-5: OEM Provided Average Cost Increases for Emergency Standby Generator Sets

HP Range	Cost of Tier 2/3 Gen-Set ($)	Tier 4i Regulatory Scenario (DPF)*		OEM Tier 2/3 Scenario (DPF)		Tier 4f Regulatory Scenario (DPF/SCR)	
		% Increase	$ Increase	% Increase	$ Increase	% Increase	$ Increase
50-174	$29,000	55%	$16,000	65%	$19,000	95%	$28,000
175-749	$67,000	105%	$71,000	55%	$36,000	125%	$85,000
750-1206	$141,000	100%	$136,000	40%	$57,000	110%	$156,000
1,207-1,999	$309,000	75%	$227,000	30%	$96,000	80%	$248,000
>2,000	$523,000	60%	$303,000	30%	$141,000	65%	$329,000

* For > 1,207hp, both SCR and DPF required.

As can be seen in Table B-5, the cost increase for an OEM supplied DPF equipped gen-sets ranges from $16,000 to $19,000 for less than 175 hp gen-sets and about $100,000 for a gen-set in the 1,207 to 1,999 hp range. The costs for OEM gen-sets with DPF and SCR are estimated to be more than 2 times the cost of DPF only gen-sets. Comparing the estimated cost increases between the end-user scenarios and the OEM scenarios, it can be seen that it will be less costly for the end user to retrofit an existing Tier 2 or 3 gen-set than for the OEMs to supply the gen-set. This cost differential helps to support the OEMs contention that it is not economically viable for them to develop and maintain a “California only” emergency standby gen-set platform with after-treatment controls.

Table B-6 below provides a summary of the estimated average cost per hp for each scenario. As is shown, on a per horsepower basis, the costs for an end user to retrofit an existing gen-set is less in most all cases than the potential costs if the gen-set with after-treatment were provided by the OEM. One reason for this cost differential is that the cost data from the OEM included research, design and manufacturing cost associated with producing a CA only product.

Table B-6: Average Cost per Horsepower for Each Scenario Investigated

HP Range	Tier 4 Interim	OEM Tier 2/3 with DPF	Tier 4 Final	Aftermarket DPF[1]	Aftermarket DPF & SCR
50-174	$143	$170	$250	$38	$118
175-749	$154	$78	$184		
750-1,206	$139	$58	$160		
1,207- 2,000	$142	$60	$155		
>2,000	$115	$54	$125		

[1] Includes installation costs

C. Cost-Effectiveness

ARB staff determined the cost-effectiveness associated with the two scenarios that entailed the end user retrofitting an existing Tier 2 or 3 engine to meet the Tier 4 standards. Because the OEMs have stated they will not provide Tier 4 emergency standby engines for the California market, in the event the ATCM is not amended, the only reasonable compliance pathway for operators would be to retrofit a new Tier 2 or 3 engines with a DPF and SCR to meet the Tier 4 Offroad Standards. In each case, the cost-effectiveness was estimated on a per engine basis by evaluating the emissions and costs impacts for the average size engine within each horsepower range. To determine the cost-effectiveness, ARB staff calculated the difference in PM and NOx emissions between the new Tier 2 or Tier 3 gen-set and the gen-set described for each scenario. For Scenario 1, which relies on DPF after-treatment technology, the entire cost was applied to PM reductions. For Scenario 2, which has both NOx and PM reductions due to the application of DPF and SCR technologies, the costs were apportioned to the estimated emission reductions based on the contribution of the technology cost to the total costs. For example, the cost of the SCR is about 2/3 of the total costs for an engine with both a DPF and SCR. Using this relationship, for an engine equipped with both a DPF and SCR, 2/3 of the cost was attributed to the NOx reductions and 1/3 of the cost to the PM reductions. Table B-7 provides a summary of the costs and cost-effectiveness for each scenario.

Table B-7: Cost-Effectiveness Associated with the Application of DPF and SCR on Emergency Standby Engines

Regulatory Scenario			**HP Range**				
			50-174	**175-749**	**750-1206**	**1207-1999**	**>2000**
	Average Horsepower:		112	462	978	1604	2630
Scenario 1: DPF Retrofit of Tier 2/3 engine	**Cost Increase Due to Controls**	PM	$4,300	$17,600	$37,200	$60,900	$99,900
		NOx	N/A	N/A	N/A	N/A	N/A
	Emission Reductions (lbs)	PM	8	33	70	115	189
		NOx	N/A	N/A	N/A	N/A	N/A
	Cost Effectiveness ($/lb)	PM	$540	$530	$530	$530	$530
		NOx	N/A	N/A	N/A	N/A	N/A
Scenario 2: DPF/SCR Retrofit of Tier 2/3 engine	**Cost Increase Due to Controls**	PM	$4,400	$18,200	$38,500	$63,100	$103,400
		NOx	$8,800	$36,300	$76,900	$126,100	$206,900
	Emission Reductions (lbs)	PM	8	33	70	115	189
		NOx	100	413	1456	2280	3740
	Cost Effectiveness ($/lb)	PM	$550	$550	$550	$550	$550
		NOx	$90	$90	$54	$56	$56

Assumptions: Emergency standby engine operates 31 hours per year at 30 percent load; 22 hours for maintenance and testing, 7 for emergency hours, and 2 for DRP. DPF costs $38/hp and SCR costs $80/hp. Scenario 2 attributes one-third of the cost to PM reductions and two-thirds to NOx reductions. SCR and DPF have 25 year life. For the SCR, it was assumed that for half of the maintenance and testing hours of operation and for all emergency hours (20 hours) the SCR was operating at full efficiency and the NOx emission rate was consistent with the Tier 4 emission standards. For one half of the maintenance and testing operation (11 hours) it was assumed the SCR was not at the correct operating temperature and the NOx levels reflected Tier 2 or Tier 3 NOx emission levels. This assumption is based on the 15 minute warm up time for typical SCR systems. Note, cost estimates are different than those in Table B-4 due to rounding

To provide perspective on these estimates, ARB staff compared the cost-effectiveness for an engine in the 175-749 hp range (see second column under “HP Range” “175-1206” heading in Table B-7) to the cost-effectiveness of regulations or programs currently being implemented by the ARB to reduce PM and NOx emissions. According to an earlier ARB survey, about 40% of all emergency standby engines are within the 175 to 749 hp range. (ARB, 2003). Table B-8 presents a comparison of the PM cost-effectiveness and Table B-9, the NOx cost-effectiveness. As can be seen, the incremental cost-effectiveness associated with the transition from Tier 2 or 3 emission standards to either the Tier 4i or Tier 4f for emergency standby engines is higher than any of the other regulations adopted by the Board. This is primarily due to the low number of hours that emergency standby engine typically operate.

Table B-8: PM Cost-Effectiveness Comparison [1]

Regulation or Airborne Toxic Control Measure	PM Cost Effectiveness ($/lb)
Stationary ATCM Incremental Cost-Effectiveness Tier 2/3 to Tier 4 for New Emergency Standby Engines	$530
In-Use Off-road Diesel Vehicle Rule[2]	$40
Solid Waste Collection Vehicle Rule	$32
Cargo Handling ATCM	$21
Ship Main/Aux/Boiler Proposal (2008)	$16
Ship Auxiliary Engine Regulation (2005)	$13
Public Fleets Rule	$160

[1] Chart taken from Fuel Sulfur and Other Operational Requirements for Ocean-Going Vessels Within California Waters and 24 Nautical Miles of the California Baseline (ARB, 2008)

[2] Attributes all regulation costs associated with diesel emission controls to PM and splits other regulation costs equally between PM and NOx.

Table B-9: NOx Cost-Effectiveness Comparison

Regulation or Airborne Toxic Control Measure	NOx Cost Effectiveness ($/lb)
Stationary ATCM Incremental Cost-Effectiveness Tier 2/3 to Tier 4 for New Emergency Standby Engines	$90
Carl Moyer Limit (2008 guidelines)	$8
Cargo Handling Equipment Rule	$1
In-use Off-Road Diesel Vehicle Regulation	$2
Commercial Harbor Craft Rule	$1
Portable Engine ATCM	$2
Public Fleet Rule	$11

Load Specific Cost-Effectiveness Calculations

Diesel engines typically have varying emissions rates that are dependent on many variables including the engine load and application. For the analysis of the emissions impacts associated with application of a DPF on a Tier 2 or 3 engine, ARB staff assumed that the PM emission rate of the engine would be equivalent to the 0.15 g/bhp-hr PM emissions standard for Tier 2 or 3 engines greater than 175 hp. This emissions rate is also the publically available emissions rate that is published on the certification executive orders and what manufacturers provide to ARB when demonstrating certification for an engine.

During the development of the proposed amendments, it was commented that when evaluating the cost-effectiveness of applying DPF after-treatment to an emergency standby engine, it is not appropriate to use the Tier 2 or 3 PM emissions limit for a particular horsepower. Rather, it was recommended that ARB staff use the emissions rate that reflects the specific load that the engine is operating. As noted above, ARB staff relied on the 0.15 g/bhp-hr PM emissions limit for a certified Tier 2 or 3 engine and assumed that is the emissions rate at a 30% load. As a check on this estimation, ARB staff collected available emissions test data at various test loads for 44 different engines. Table B-10 shows the emission rates and the reported values at each load. Using the average emission rates for the 10% and 25% load points, ARB staff calculated the PM cost-effectiveness for a 600 hp engine using the same assumptions for annual hours of operation and DPF life as was used above to generate the values presented in Table B-7. For comparison purposes, ARB staff also recalculated the cost-effectiveness with a 0.15 g/bhp-hr PM emission rate and assumed a 10% and 25% load to provide a more unbiased comparison.

Table B-10: Diesel Generator Engine Emissions Test Data at Different Load Points[5]

No.	MY	Power	10% load	25% load	50% load	75% load	100% load
1	2007	50	0.25	0.21	0.16	0.16	0.25
2	2010	100	0.25	0.21	0.20	0.19	0.17
3	2007	147	0.27	0.15	0.12	0.09	0.07
4	2010	150	0.19	0.16	0.09	0.08	0.07
5	2010	250	0.51	0.43	0.20	0.05	0.04
6	2010	298	0.87	0.40	0.22	0.04	0.04
7	1985	300	0.68	0.43	0.30	0.20	0.19
8	1999	300	0.17	0.07	0.09	0.08	0.07
9	1991	300	0.41	0.21	0.10	0.09	0.18
10	1986	300	1.25	0.32	0.07	0.07	0.10
11	2010	310	0.29	0.23	0.10	0.05	0.03
12	2000	350	0.96	0.26	0.18	0.17	0.15
13	1999	350	0.36	0.16	0.08	0.07	0.06
14	1991	350	0.77	0.48	0.36	0.18	0.11
15	2000	350	0.74	0.26	0.26	0.23	0.20
16	2000	350	0.73	0.28	0.24	0.24	0.18
17	2000	350	0.74	0.24	0.22	0.20	0.16
18	2005	350	0.17	0.15	0.08	0.07	0.07
19	2010	351	0.12	0.12	0.04	0.04	0.06
20	1990	360	0.68	0.37	0.34	0.28	0.25
21	2005	400	0.16	0.13	0.08	0.07	0.07
22	1990	450	1.31	0.62	0.38	0.40	0.65
23	2005	450	0.13	0.11	0.07	0.07	0.04
24	2005	500	0.13	0.11	0.07	0.07	0.07
25	2010	511	0.24	0.54	0.10	0.12	0.09
26	1998	545	0.57	0.26	0.17	0.20	0.28
27	1998	545	0.70	0.30	0.20	0.23	0.35
28	2010	600	0.32	0.27	0.11	0.07	0.05
29	2010	750	0.30	0.25	0.23	0.19	0.16
30	2010	800	0.30	0.25	0.23	0.19	0.16
31	2010	1000	0.30	0.25	0.20	0.16	0.15
32	2002	1000	0.86	0.36	0.19	0.10	0.07
33	2010	1250	0.51	0.43	0.12	0.09	0.05
34	2000	1500	0.90	0.39	0.23	0.14	0.09
35	2010	1500	0.49	0.42	0.08	0.08	0.05
36	2010	1750	0.33	0.28	0.19	0.08	0.04
37	2010	2000	0.32	0.27	0.16	0.04	0.05
38	2000	2000	0.98	0.34	0.18	0.09	0.07
39	2010	Varies	0.60	0.35	0.15	0.11	0.06
40	2010	Varies	0.28	0.32	0.24	0.06	0.04
41	2010	Varies	0.32	0.17	0.09	0.03	0.05
AVERAGES	**g/KW-hr**	**611 KW**	**0.50**	**0.28**	**0.17**	**0.13**	**0.12**
	g/BHP-hr	**819 HP**	**0.37**	**0.21**	**0.13**	**0.09**	**0.09**

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[5] Engine emission data provided by Caterpillar, Inc. (Caterpillar, 2010), Cummins, Inc. (Cummins, 2010), John Deere Power Systems (John Deere, 2010), MTU Detroit Diesel (Detroit Diesel, 2010), and "Emissions of regulated pollutants from in-use diesel back-up generators." (U.C. Riverside, 2006)

Using the data in Table B-10, ARB staff calculated the PM cost-effectiveness for a typical 600 hp engine assuming the engine emitted at the average PM emissions rate for the 10% load (0.37 g/bhp-hr) and for the 25% load (0.21 g/bhp-hr). The cost-effectiveness was calculated according to the following equations:

(1) Total PM Reductions = (HP x L) x (EF_{PM} - (EF_{PM} x .85)) x (1lb/454g) x LF x H

Where

HP = horsepower of an emergency standby engine (600 hp)
L = operational load of engine (10% and 25%)
EF = emission rate of diesel PM at the specified load (g/bhp-hr)
LF = expected DPF life (25 years)
H = annual hours of operation (31 hrs)

(2) Total Cost Effectiveness = (HP x C) / (Total PM Reductions)

Where

HP = horsepower of an emergency standby engine (600 hp)
C = cost of DPF ($38 per hp)

Table B-11: Comparison of PM Cost-Effectiveness Calculated with Load Specific PM Emission Rates to Cost-Effectiveness Calculated Using the PM Emission Standard

Load	HP	PM Emission Rate g/bhp-hr	PM Emission Rate with DPF g/bhp-hr	Total PM Reduced Over 25 Years (lbs)	Total DPF Cost	Cost Effectiveness ($/lb)
10%	600	0.37	0.05	32	$22,800	$710
25%		0.21	0.03	46		$495
10%		0.15	0.01	14		$1,630
25%		0.15	0.01	36		$630
30%		0.15	0.01	43		$530

Table B-11 provides a summary of the cost-effectiveness values. The first two rows present the cost effectiveness calculated using the equation above and the average PM emissions rates at 10% and 25% load presented in Table B-10. The last three rows provide the cost-effectiveness values at 10%, 25%, and 30% loads that were calculated using the approach ARB staff used to evaluate the cost-effectiveness of DPF after-treatment on emergency standby engines *i.e*. assume the engine has the same PM emission rate equivalent to 0.15 g/bhp-hr at all loads. As can be seen, at the 25% load, using the load specific values reduces the cost-effectiveness by about 20% as compared to the cost-effectiveness calculated assuming the engine emits at the 0.15 g/bhp-hr emission rate. The difference is more significant at a 10% load, with cost-effectiveness calculated using the load-specific values being about 60 percent lower than that calculated using the 0.15 g/bhp-hr PM emission rate. However, in each case, it is clear that the cost effectiveness is still prohibitively high compared to previous regulations as can be seen in Table B-8.

D. Direct Drive Fire Pumps

The analysis above focused on emergency standby generator sets. The same costs estimates and conclusions regarding cost-effectiveness also apply to emergency direct-drive fire pump engines. However, as discussed below, there are also other factors concerning the application of SCR and DPF on emergency standby direct drive fire pumps. Due to the substantial cost and time to develop Tier 4 engines specifically for fire pump applications, and the relatively small market for these engines in California, (about 100 new engines per year), suppliers have indicated that it may not be economically viable for them to offer new fire pump engines in California if the Tier 4 standards are implemented. (Clarke, 2010a)(Clarke, 2010b)

Emergency standby fire pump engines are unique in that they must be certified to the National Fire Protection Association (NFPA) requirements and certified by an independent produce safety organization. Engine manufacturers and fire pump system suppliers work together to develop and certify these engines to NFPA requirements, a process that can take many months or years. Having an added SCR or DPF device on the fire pump engine would likely complicate and lengthen this process.

On the engine manufacturer side, achieving certification typically involves changes to the software that controls the engine. For example, the engine may be programmed to deactivate engine protection features during a fire (such as stopping the engine when it is operating outside of normal parameters), while activating these features during normal maintenance and testing runs. Electronically-controlled engines may also be supplied with two engine control units to provide redundancy in case one fails. Fire pump engines may also be designed without a radiator, instead utilizing the cooling water they are designed to pump. In addition to the development time with the engine manufacturer, the fire pump supplier must certify the engine to the requirements of NFPA 20, Standard for the Installation of Stationary Pumps for Fire Protection. Third party certification companies such as Underwriters Laboratories (an independent product safety certification organization) and FM Global (an insurance company) approve (or “list”) products to the NFPA 20 requirements. These organizations certify each component in fire protection systems, including the engine, fire pump, pump control unit, coupling between the engine and pump. For example, the engines used in fire pumps must be certified by the company to ensure that the engine power is at least 10 percent greater than the maximum power required by the pump under any conditions of pump load (among other requirements). Fire pump system suppliers typically seek separate certifications for both FM Global and UL. FM Global certification may be needed for manufacturing sites, while UL may be needed for other applications. Since the supplier wants their fire pump systems to be acceptable in all possible applications, certification to both FM Global and UL is typical.

E. Findings

Based on the analysis of the feasibility, costs, and cost-effectiveness associated with the application of DPF and SCR after-treatment devices on emergency standby engines, ARB staff has the following findings.

- Applications of DPFs on emergency standby engines are technically feasible and there are currently about 300 emergency standby engines in California that have DPFs installed.

- There is very limited application of SCR on emergency standby engines. ARB staff is aware of a few applications on larger emergency standby engines in California. However, ARB staff believes that while the current generation of SCR systems may be technically feasible, there are significant economic and operational constraints to the routine use of SCR on emergency standby engines. This is because the majority of operating hours for emergency standby engines occur during short 15 to 30 minute maintenance and testing checks are at low engine loads. In most cases, the temperature needed for the SCR catalyst to function will not be reached during this operation and the SCR will not provide the expected NOx reductions.

- Tier 4 engines that rely on after-treatment technology for emergency standby applications will not be available from the original equipment manufacturers. Representatives from the EMA have indicated that it will not be economically viable for engine manufacturers to develop and maintain a Tier 4 emergency standby engine platform for California. Because of this, staff has concluded that Tier 4 engines for emergency standby applications will not be available "off-the-shelf." Rather, each owner or operator will need to purchase a new Tier 2 or Tier 3 engines and then work with suppliers to retrofit the engine with a DPF and/or SCR to meet the Tier 4 emission standards for all pollutants.

- It is not cost-effective to routinely apply DPF or SCR after-treatment technologies on emergency standby engines. The costs of SCR and DPF after-treatment technology are very high and given the low number of hours that a typical emergency standby engine operates, about 31 hours per year, the cost-effectiveness is significantly higher than other ARB diesel engine regulations.

Based on the analysis, and those of U.S. EPA (EPA, 2006), ARB staff believes it is appropriate to more closely align the ATCM emissions standards for new emergency standby engines with those in the NSPS that do not require after-treatment based emission standards. However, ARB staff believes it is also important to continue provide the districts with the ability to impose more stringent conditions on a site-specific basis where the additional controls are warranted.

REFERENCES

(ARB, 2003) Airborne Toxic Control Measure for Stationary Compression-Ignition Engines, California Air Resources Board, September 2003

(Caterpillar, 2010) Telephone Conversation with Gordon Gerber, Global Engine Emissions Manager, Caterpillar, Inc., Dated August 31, 2010

(Clarke, 2010a) Telephone Conversation with John Whitney – Clarke Fire Protection Products, Inc., Dated June 23, 2010

(Clarke, 2010b) Telephone Conversation with John Whitney – Clarke Fire Protection Products, Inc., Dated June 30, 2010

(Cummins, 2010) Telephone Conversation with Mike Brand, Director - Regulatory Affairs, Cummins, Inc., Dated August 31, 2010

(Detroit Diesel, 2010) Telephone Conversation with Frank Seymour, Compliance & Regulatory Affairs, MTU Detroit Diesel, Dated August 31, 2010

(District, 2010) Summary Table of District SCR and DPF Installations. District 2010.xls, Last modified January 2010

(John Deere, 2010) Telephone Conversation with Rick Bishop, Environmental Compliance, John Deere Power Systems, Dated August 31, 2010

(Johnson Matthey, 2010) Johnson Matthey Email Correspondence with Wilson Chu. Dated August 2, 2010

(Miratech, 2010) Miratech Email Correspondence with Nick Detor, Dated August 1, 2010

(Rypos, 2010) Telephone Conversation with Greg Korst, Applications Engineer, Rypos, Dated July 26, 2010

(U.C. Riverside 2006) Sandip D. Shah. David R. Cocker III. Kent C Johnson. John M. Lee. Bonnie L. Soriano. J. Wayne Miller. *Emissions of regulated pollutants from in-use diesel back-up generators.* Department of Chemical and Environmental Engineering, University of California, Riverside. Bourns College of Engineering, Center for Environmental Research and Technology. California Air Resources Board. Published July 2006

(U.S. EPA, 2006) Cost per Ton for NSPS for Stationary CI ICE. Alpha-Gamma Technologies, Inc. May 16, 2006