EPA emissions regulations:

What they mean for standby, prime and distributed power systems

> **White Paper**

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On July 11, 2006, the EPA finalized the New Source Performance Standards (NSPS) to regulate emissions from stationary diesel engines. Starting from January 1, 2007, the NSPS harmonizes emissions requirements for stationary diesel engines with the existing EPA nonroad regulations. In the NSPS, the EPA also specified requirements for an interim period through January 1, 2007 to transition to these new stationary engine regulations. Concurrently, the EPA also proposed regulations for stationary spark-ignited gas engines, which will be finalized by December 20, 2007. This paper explains how the Environmental Protection Agency's (EPA) New Source Performance Standards apply to diesel and spark-ignited engines used in generator sets.

Regulations reduce NO_x emissions

Exhaust emissions from diesel-powered generators include oxides of nitrogen (NO_x), hydrocarbons (HC), carbon monoxide (CO) and particulate matter (PM) that would include any visible smoke and soot. Current standards enacted by the EPA and various state agencies have mandated significant reductions in all these substances – particularly NO_x – in an effort to reduce impact on the environment and public health. The most stringent of these regulations will ultimately reduce diesel NO_x emissions to be on par with prime movers burning natural gas equipped with the Best Available Control Technology (BACT).

As of the date of this document's publication, Cummins Power Generation offers generator sets from 15 kW to 2700 kW that meet all applicable Tier levels established by the EPA for stationary and nonroad applications. Compared to older engines, NO_x and PM emissions from stationary and nonroad diesel engines have been reduced up to 85 percent to meet EPA standards.

Diesel-powered generator sets remain the preferred choice for standby and emergency power systems around the world. With the growth of applications in recent years involving distributed generation, more diesel generator sets are being used for utility peaking and commercial load-shedding due to their proven reliability, low life-cycle cost, high efficiency, ready availability, ease of installation, operational flexibility and high-quality electrical performance.

The regulatory landscape

Until the issuance of the final NSPS on July 11, 2006, regulations for stationary diesel engines, primarily used for power generation, were in sharp contrast to regulations for nonroad diesel engines. Prior to the new standards, there were no federal emissions regulations for stationary diesel engines. Emissions regulations for stationary engines were usually governed by state and local permitting authorities and varied by the annual operating hours for the application. The exact number of permissible operating hours varied by state and locale, but as an example, base-load generators running in excess of 2,000 hours per year in areas with the worst air quality faced the most stringent local emissions standards. Load management or peaking facilities running up to 1,000 hours per year faced slightly less stringent regulations. Standards for emergency standby generators operating only 200 hours per year had the most attainable permitting requirements. These general standards were established by local authorities in response to an EPA requirement for clean air standards. EPA's NSPS stationary emissions standards are intended to help local authorities meet EPA's clean air standards in regions that are non-compliant.

Stationary vs. nonroad (mobile) applications

The EPA "nonroad" category of engines was established to describe engines used in mobile equipment such as farm equipment, construction equipment, trailerized generator sets and other portable industrial engines used in temporary off-road applications. The EPA created and established standards for the nonroad category because local permitting authorities only had jurisdiction over stationary sources.

Stationary engines are defined as any engine that is permanently installed and used as a power source. This category includes standby generator sets, on-site prime and distributed energy power systems, and a wide variety of industrial engines mounted on permanent bases or foundations. Trailerized engines and generator sets are considered to be stationary when they are installed at a single location for more than 12 months. After January 1, 2007, both the nonroad regulations and the stationary engine regulations will be essentially identical and based on the existing nonroad regulations.

Interim period established

The full provisions of the NSPS are effective January 1, 2007. However, the rapid enactment of the regulations for stationary generator sets has made it difficult for some manufacturers to adjust their factory build schedules. As a result, the EPA established an interim period that addressed the manufacturers' needs while encouraging the introduction of lower-emitting products to the field as soon as possible.

During the interim period, the NSPS for stationary diesel engines applies to each diesel engine for stationary use that was both ordered after July 11, 2005, and built after April 1, 2006. All stationary generators using engines ordered and built after these respective dates had to comply with EPA nonroad Tier 1 emissions requirements. Beginning January 1, 2007, all diesel engines used in generator sets are required to be built to the prevailing regulations for EPA nonroad engines. The regulation levels (Tier levels) depend on the engine horsepower. There are two significant exceptions: 1) stationary engines over 3000 hp will remain at Tier 1 until 2011; and 2) the intent is that requirements for stationary emergency standby generators will not advance beyond the last Tier that requires no aftertreatment (i.e., Tier 3).

Spark-ignited gas engines

On June 12, 2006, the EPA proposed new rules to regulate emissions from stationary spark-ignited gas engines. Although this rule will not be finalized until December 20, 2007, its provisions to regulate emissions levels for non-emergency engines (used in peaking and landfill gas) and engines below 25 hp will become effective July 1, 2007. From January 1, 2009, spark-ignited gas engines used in stationary emergency applications will be required to be EPA-certified.

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Figure 1

Nonroad and stationary emissions regulations schedule

U.S. EPA Beginning January 1, 2007, (red bar) all stationary and nonroad regulations are harmonized.

kWM	(HP)	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
0 - 7	(0 - 10)		(7.5) / 8.0 / 0.80			(7.5) / 6.6 / 0.40									
8 - 18	(11 - 24)		(7.5) / 6.6 / 0.80												
19 - 36	(25 - 48)	(7.5) / 5.5 / 0.60				(7.5) / 5.0 / 0.30					(4.7) / 5.0 / 0.03				
37 - 55	(49 - 74)	(7.5) / 5.0 / 0.40				(4.7) / 5.0 / 0.30									
56 - 74	(75 - 99)					(4.7) / 5.0 / 0.40				3.3 / 0.19 / 5.0 /0.02			0.40 / 0.19 / 5.0 / 0.02		
75 - 129	(100 - 173)	(6.6) / 5.0 / 0.30			(4.0) / 5.0 / 0.30										
130 - 224	(174 - 301)	(6.6) / 3.5 / 0.20			(4.0) / 3.5 / 0.20				2.0 / .019 / 3.5 / 0.02			0.40 / 0.19 / 3.5 / 0.02			
225 - 449	(302 - 602)	(6.4) / 3.5 / 0.20			(4.0) / 3.5 / 0.20										
450 - 560	(603 - 751)	(6.4) / 3.5 / 0.20			(4.0) / 3.5 / 0.20										
>560	(>751)	9.2 / 1.3 / 11.4 / 0.54			(6.4) / 3.5 / 0.20				3.5 / 0.40 / 3.5 / 0.10 *0.67 / 0.40 / 3.5 / 0.10 (>1207hp)[a]*			(3.5) / 0.19 / 3.5 / 0.04 *0.67 / 0.19 / 3.5 / 0.03 (>751hp)[b]*			

Tier 1 Tier 2 Tier 3 Tier 4 Interim Tier 4 Final

a. Applies to portable power generation >1207hp. b. Applies to portable power generation >751hp.

NO_x / HC / CO / PM (g/kW-hr)
(NO_x + HC) / CO / PM (g/kW-hr)
[Conversion: (g/kW-hr) x 0.7457 = g/bhp-hr]
Separate NO_x and HC standards separated by a slash.
Combined NO_x and HC standards denoted in parentheses "( )".

Figure 1 summarizes the EPA emissions regulations for both EPA nonroad and stationary diesel engine generators out to 2017. Due to the interim regulations established by EPA, engines used in all stationary generator sets that were both ordered after July 11, 2005, and built after April 1, 2006, must comply with Tier 1 regulations. Beginning with engines built on January 1, 2007, all stationary generators with engine ratings of 10-99 hp must comply with Tier 2 regulations; all generators with engines in the range of 100-751 hp must comply with Tier 3 regulations; and generators with engines in the range of 752-3000 hp will require Tier 2 certification. Stationary engines over 3000 hp will remain at Tier 1 until more stringent requirements become effective in 2011.

State and local authorities may still act further

Although NSPS establishes for the first time uniform federal standards for emissions from stationary generator sets, these regulations do not prevent state and local authorities from imposing even more restrictive standards based on prevailing local air quality conditions. In the U.S., certain state and local emissions standards for diesel-powered generator sets require an additional level of control, primarily for NO_x and PM. While EPA-designated "nonattainment areas" represent a fraction of the land area of the country, they are typically heavily populated areas – areas where diesel standby and peaking generator sets are most likely to be deployed. In effect, these nonattainment areas have served to drive development of NO_x and PM control strategies and to economically bring them to market in advance of the EPA standards alone.

National Ambient Air Quality Standards

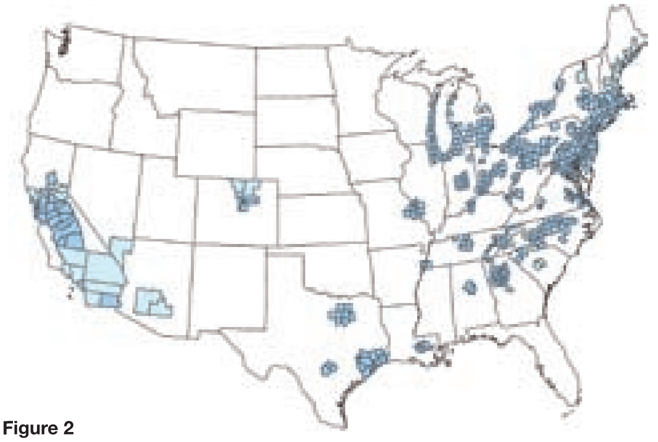

Figure 2
Ozone nonattainment status:
Part of County Whole County Attainment

Figure 2 shows counties designated nonattainment for the 8-hour ozone standard. NO_X — a recognized precursor to ozone — is more strictly controlled in areas with higher ozone levels.

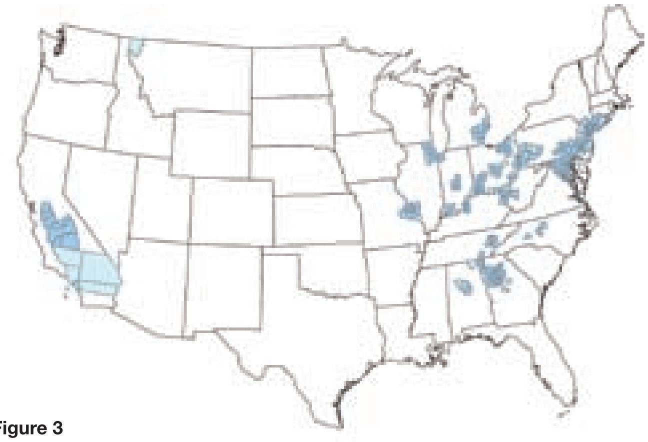

Figure 3
PM nonattainment status:
Part of County Whole County Attainment

Figure 3 shows counties designated nonattainment for particulate matter ($PM_{2.5}$). $PM_{2.5}$ designates particulate matter (primarily soot particles) that is less than 2.5 microns in size.

Attainment vs. nonattainment

The U.S. metropolitan areas that meet the National Ambient Air Quality Standards (NAAQS) are said to be in "attainment" for specific contaminants. Those areas not meeting the standards are said to be in "nonattainment." States having nonattainment areas must develop State Implementation Plans (SIPs) showing how those areas will be brought into attainment. The EPA's Office of Air Quality Planning and Standards (OAQPS) provides guidance for stationary source emissions reductions upon which the SIPs can be based.

Ozone remains the most significant air pollution problem in the U.S. and is partially attributable to NO_X emissions. In areas which have attained the NAAQS for ozone, EPA permitting guidelines generally require a Prevention of Significant Deterioration (PSD) review to assist the local authorities in maintaining attainment. For those areas in nonattainment for ozone, the EPA has established five degrees of nonattainment severity, each of which has different requirements. Further, local authorities can mandate more stringent guidelines than the EPA requires. For nonattainment areas, a more extensive New Source Review (NSR) is required for major new sources, or modifications to sources, having the potential to emit more than designated thresholds.

Figure 2 illustrates the areas in the U.S. that have been unable to attain the EPA-mandated standards for ground-level ozone, and where the control of NO_X, a recognized precursor to ozone, is a major concern. These areas are therefore designated as ozone nonattainment areas and are further classified by the extent of nonattainment – extreme, severe, serious, moderate and marginal. Generator set applications in these nonattainment areas face the most stringent emissions regulations and often require the Best Available Control Technology (BACT) to be in compliance with state and local permits. These BACT measures often include Selective Catalytic Reduction (SCR) aftertreatment, particulate traps and the use of low-sulfur fuels for non-emergency diesel generators.

Figure 3 illustrates the nonattainment designations for particulate matter ($PM_{2.5}$). $PM_{2.5}$ designates particulate matter (primarily soot particles) that is less than 2.5 microns in size. Although PM emissions from diesel generator sets have been reduced 70 percent by the introduction of Tier 1 models, further PM reduction to meet local requirements could be accomplished through the use of even lower-emitting engines or through the use of particulate traps on the exhaust.

Background on diesel emissions control strategies

The real challenge in designing today's diesel engines involves a trade-off between NO_X and PM emissions. Most engine modifications that decrease NO_X have a tendency to increase PM. Conversely, techniques to reduce PM tend to increase the production of NO_X. Both are linked by combustion temperatures: As in-cylinder temperatures increase, PM goes down but NO_X goes up; as temperatures decrease, NO_X goes down but PM goes up. The following control strategies are primarily concerned with optimizing the control of these two constituents, either during combustion or after.

Engine modifications – All engine modification strategies have been aimed at optimizing the combustion process while producing the least amounts of both NO_X and PM per unit of power output. Following are the major strategies currently employed that enable diesel manufacturers to achieve Tier 3-level emissions reductions.

- *Electronic engine controls* – The addition of electronic sensors and microprocessor-based controls has greatly improved fuel efficiency and power output while decreasing the production of both NO_X and PM. By controlling fuel quantity, injection timing, turbocharger boost pressure and other factors, electronic engine controls maintain optimum combustion efficiencies by compensating for load, temperature, fuel energy content, barometric pressure and even engine wear.
- *Injection systems* – Injection timing, injection pressure, nozzle design and electronic injection systems have all proved significant in controlling both NO_X and PM. Retardation of injection timing along with increased injection pressure has been shown to reduce NO_X without significantly increasing the production of hydrocarbons (HC) or PM. Higher injection pressures and multiple injection events per cycle improve fuel atomization and combustion chamber penetration that simultaneously improve fuel economy while reducing PM.
- *Combustion chamber geometry* – Combustion chamber design goals include achieving the optimum compression ratio and thorough mixing of fuel and air prior to combustion. Designs that optimize the air swirl and turbulence provide the best mixing and therefore the lowest emissions consistent with high power output.
- *Turbocharging systems* – All medium and large diesel generator sets employ turbocharging to boost power, improve combustion efficiency and reduce emissions. The most sophisticated systems use aftercoolers – water-cooled or air-cooled heat exchangers that increase the density of the charge air and therefore increase specific power output.
- *Exhaust Gas Recirculation (EGR)* – EGR is a well-proven method of reducing NO_X in internal combustion engines. By recycling a portion of the inert gases of the exhaust gas stream with incoming engine air, combustion temperatures are reduced and, therefore, so is NO_X formation. While not employed widely in stationary diesel engines at the present time, EGR may be used on selected engines to achieve compliance with EPA regulations.

Aftertreatment strategies – For larger engine size categories, achievement of Tier 3 stationary and nonroad levels of NO_X and PM are about the maximum limit for diesel engine in-cylinder control strategies. To reach Tier 4 levels of NO_X and PM, aftertreatment of exhaust gas will be necessary. The following strategies have already achieved a practical level of commercialization in a variety of applications. Most aftertreatment strategies require the use of low-sulfur diesel fuel to prevent catalyst contamination.

- *Selective Catalytic Reduction (SCR) systems* – Already in wide use on stationary diesel engines, SCR systems incorporating aqueous urea injection into the exhaust stream passing over a suitable catalyst reduce NO_X up to 90 percent. Systems consist of an SCR catalyst, urea injection system, urea tank, pump and a control system.
- *PM traps* – Diesel particulate matter (PM) traps are designed to physically capture PM from the exhaust stream. They can either be simple mechanical filters requiring frequent replacement, or they can be catalytic filters that provide periodic or continuous oxidation (regeneration) of the trapped particulates into CO_2. PM traps with continuous regeneration have already reached a high level of commercialization and are being employed on stationary diesel engines in areas with strict PM emissions regulations. Ultra-low sulfur diesel fuel is needed to prevent contamination of the conversion catalysts. However, filtration efficiencies up to 90 percent have been demonstrated.

About the author

Jim Iverson is a Senior Applications Engineer for Cummins Power Generation. He develops technical input for published literature and software, publishes technical papers on relevant industry topics, provides application engineering support to customers, and participates in domestic industry codes and standards development. An employee since 1976, he previously managed transfer switch design, systems engineering, switchgear and controls, and technical marketing and sales. He holds a Masters in Engineering Science, and a Bachelor's in Electrical Engineering.

Fuel modifications – Modified and substitute diesel fuels have shown some potential to lower emissions of NO_X and PM. While not total solutions, certain modified fuels may contribute to lower emissions.

- *Biodiesel* – This is defined as the mono alkyl esters of long-chain fatty acids derived from renewable vegetable oils and animal fats. Blended with normal diesel fuel in concentrations up to 5 percent, biodiesel performs well in most diesel engines. In greater concentrations, fuel cost and engine life are concerns. Biodiesel helps to reduce overall CO_2 production because it is derived from a renewable source. However, NO_X emissions are actually slightly higher using biodiesel.
- *Ultra-low sulfur diesel fuel* – While sulfur in diesel exhaust in the form of SO_2 or sulfate particles is not a significant environmental concern, sulfates generally interfere with most aftertreatment strategies involving catalysts. To achieve Tier 3 emissions levels for both PM and NO_X, it is generally agreed that ultra-low sulfur fuels (approximately 15 ppm) will be required. Availability of ultra-low sulfur fuels is expected to increase in the near future due to increasing use of sensitive catalytic systems in both on-highway and stationary diesel engines. Most aftertreatment strategies require the use of low-sulfur diesel fuel to prevent catalyst contamination.

Conclusions and recommendations

Beginning with engines built on January 1, 2007, all generators with engine ratings of 10-99 hp must comply with Tier 2 regulations; all generators with engines in the range of 100-751 hp must comply with Tier 3 regulations; and all generators with engines in the range of 752-3000 hp will require Tier 2 certification. Stationary engines over 3000 hp will remain at Tier 1 until 2011.

Strategies are already in place to accomplish these and future emissions reduction goals mandated by the EPA through new engine controls and aftertreatment of the exhaust. Thanks to the technological refinements taking place today, the electric power industry will continue to enjoy the performance advantages that diesel generators offer well into the foreseeable future.

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