

use of both retrofit and original equipment CDPF systems for highway vehicles.^{137 138 139} However, it is possible that for some nonroad applications the engine-out PM rate may exceed the soot oxidation rate, even with low sulfur diesel fuel and the best catalyst technologies. Should this occur, successful regeneration requires that either engine-out PM rates be decreased or exhaust temperatures be increased, both feasible strategies. In fact, we expect both to occur as highway based technologies are transferred to nonroad engines. As discussed earlier, engine technologies to lower PM emissions while improving fuel consumption are continuously being developed and refined. As these technologies are applied to nonroad engines driven by both new emission standards and market pressures for better products, engine-out PM rates will decrease. Similarly, techniques to raise exhaust temperatures periodically in order to initiate soot oxidation in a PM filter have been developed for highway diesel vehicles as typified by the PSA system used on more than 400,000 vehicles in Europe.^{140 141}

During our 2002 Highway Diesel Progress Review, we investigated the plans of highway engine manufacturers to use CDPF systems to comply with the HD2007 emission standards for PM. We learned that all diesel engine manufacturers intend to comply through the application of CDPF system

technology. We also learned that the manufacturers are developing means to raise the exhaust temperature, if necessary, to ensure that CDPF regeneration occurs.¹⁴² These technologies include modifications to fuel injection strategies, modifications to EGR strategies, and modifications to turbocharger control strategies. These systems are based upon the technologies used by the engine manufacturers to comply with the 2004 highway emission standards. In general, the systems anticipated to be used by highway manufacturers to meet the 2004 emission standards are the same technologies that engine manufacturers have indicated to EPA that they will use to comply with the Tier 3 nonroad regulations (e.g., electronic fuel systems).¹⁴³ In a manner similar to highway engine manufacturers, we expect nonroad engine manufacturers to adapt their Tier 3 emission control technologies to provide back-up regeneration systems for CDPF technologies in order to comply with the standards we are proposing today. We have estimated costs for such systems in our cost analysis.

Emission levels from CDPFs are determined by a number of factors. Filtering efficiencies for solid particle emissions like soot are determined by the characteristics of the PM filter, including wall thickness and pore size. Filtering efficiencies for diesel soot can be 99 percent with the appropriate filter design.¹⁴⁴ Given an appropriate PM filter design the contribution of the soot portion of PM to the total PM emissions are negligible (less than 0.001 g/bhp-hr). This level of soot emission control is not dependent on engine test cycle or operating conditions due to the mechanical filtration characteristics of the particulate filter.

Control of the SOF portion of diesel soot is accomplished on a CDPF through catalytic oxidation. The SOF portion of diesel PM consists of primarily gas phase hydrocarbons in engine exhaust due to the high temperatures and only forms particulate in the environment when it condenses. Catalytic materials applied to CDPFs can oxidize a substantial fraction of the SOF in diesel PM just as the SOF portion would be oxidized by a DOC. However, we

believe that for engines with very high SOF emissions the emission rate may be higher than can be handled by a conventionally sized catalyst resulting in higher than zero SOF emissions. If a manufacturer's base engine technology has high oil consumption rates, and therefore high engine-out SOF emissions (i.e., higher than 0.04 g/bhp-hr), compliance with the 0.01 g/bhp-hr emission standard proposed today may require additional technology beyond the application of a CDPF system alone.¹⁴⁵

Modern highway diesel engines have controlled SOF emission rates in order to comply with the existing 0.1 g/bhp-hr emission standards. For modern highway diesel engines, the SOF portion of PM is typically on a small fraction of the total PM emissions (less than 0.02 g/bhp-hr). This level of SOF control is accomplished by controlling oil consumption through the use of engine modifications (e.g., piston ring design, the use of 4-valve heads, the use of valve stem seals, etc.).¹⁴⁶ Nonroad diesel engines may similarly need to control engine-out SOF emissions in order to comply with the standard proposed today. The means to control engine-out SOF emissions are well known and have additional benefits, as they decrease oil consumption reducing operating costs. With good engine-out SOF control (i.e., engine-out SOF < 0.02 g/bhp-hr) and the application of catalytic material to the DPF, SOF emissions from CDPF equipped nonroad engines will contribute only a very small fraction of the total tailpipe PM emissions (less than 0.004 g/bhp-hr). Alternatively, it may be less expensive or more practical for some applications to ensure that the SOF control realized by the CDPF is in excess of 90 percent, thereby allowing for higher engine-out SOF emission levels.

The best means to reduce sulfate emissions from diesel engines is by reducing the sulfur content of diesel fuel and lubricating oils. This is one of the reasons that we have proposed today to limit nonroad diesel fuel sulfur levels to be 15ppm or less. The catalytic material on the CDPF is crucial to

¹³⁷ "Particulate Traps for Construction Machines, Properties and Field Experience," 2000, SAE 2000-01-1923.

¹³⁸ Letter from Dr. Barry Cooper, Johnson Matthey, to Don Kopinski, U.S. EPA. Copy available in EPA Air Docket A-2001-28.

¹³⁹ EPA Recognizes Green Diesel Technology Vehicles at Washington Ceremony, Press Release from International Truck and Engine Company, July 27, 2001. Copy available in EPA Air Docket A-2001-28.

¹⁴⁰ There is one important distinction between the current PSA system and the kind of system that we project industry will use to comply with the Tier 4 standards. The PSA system incorporates a cerium fuel additive to help promote soot oxidation. The additive serves a similar function to a catalyst to promote soot oxidation at lower temperatures. Even with the use of the fuel additive passive regeneration is not realized on the PSA system and an active regeneration is conducted periodically involving late cycle fuel injection and oxidation of the fuel on an up-front diesel oxidation catalyst to raise exhaust temperatures. This form of supplemental heating to ensure infrequent but periodic PM filter regeneration has proven to be robust and reliable for more than 400,000 PSA vehicles. Our 2002 progress review found that other manufacturers will be introducing similar systems in the next few years without the use of a fuel additive.

¹⁴¹ Nino, S. and Lagarrigue, M. "French Perspective on Diesel Engines and Emissions," presentation at the 2002 Diesel Engine Emission Reduction workshop in San Diego, California, Air Docket A-2001-28.

¹⁴² Highway Diesel Progress Review, United States Environmental Protection Agency, June 2002, EPA 420-R-02-016. Copy available in EPA Air Docket A-2001-28.

¹⁴³ "Nonroad Diesel Emissions Standards Staff Technical Paper", EPA420-R-01-052, October 2001. Copy available in EPA Air Docket A-2001-28.

¹⁴⁴ Miller, R. et. al, "Design, Development and Performance of a Composite Diesel Particulate Filter," March 2002, SAE 2002-01-0323.

¹⁴⁵ SOF oxidation efficiency is typically better than 80 percent and can be better than 90 percent. Given a base engine SOF rate of 0.04 g/bhp-hr and an 80 percent SOF reduction a tailpipe emission of 0.008 can be estimated from SOF alone. This level may be too high to comply with a 0.01 g/bhp-hr standard once the other constituents of diesel PM (soot and sulfate) are added. In this case, SOF emissions will need to be reduced engine-out or SOF control greater than 90 percent will need to be realized by the CDPF.

¹⁴⁶ Hori, S. and Narusawa, K. "Fuel Composition Effects on SOF and PAH Exhaust Emissions from DI Diesel Engines," SAE 980507.