WRITTEN COMENTS
OF THE
MANUFACTURERS OF EMISSION CONTROLS ASSOCIATION
ON TRANSPORT CANADA'S PROPOSED RULEMAKING TO
CONTROL EMISSIONS OF AIR POLLUTION FROM NEW LOCOMOTIVE ENGINES

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MECA is pleased to present testimony in support of Transport Canada's proposals covering future emission standards for locomotive diesel engines that align with U.S. EPA's Tier 3 and 4 locomotive regulations adopted in 2008. We believe an important opportunity exists to significantly reduce emissions from new locomotive engines sold in Canada by utilizing an engineered systems approach that incorporates and combines advanced engine designs, advanced emission control technology, and ultra-low sulfur diesel fuel.

MECA is a non-profit association made up of the world's leading manufacturers of mobile source emission controls. MECA member companies have over 30 years of experience and a proven track record in developing and commercializing exhaust emission control technologies. A number of our members have extensive experience in the development, manufacture, and commercial application of emission control technologies for diesel engines, including diesel engines used in nonroad applications. Our members have partnered with vehicle and engine manufacturers to make "clean diesel" cars and trucks a reality here in North America. A recent survey of MECA's members revealed that our industry has invested more than $2 billion in R & D and capital expenditures to develop, optimize, and commercialize advanced emission control technology to substantially reduce emissions from on-road and off-road diesel engines.

Technologies to reduce diesel emissions, such as diesel particulate filters (DPFs), diesel oxidation catalysts (DOCs), NOx adsorber catalysts, and selective catalytic reduction (SCR) systems, are commercially available today. These emission control technologies have already been installed on millions of new light-duty and heavy-duty vehicles and equipment and as retrofit technology on hundreds of thousands of existing on-road and off-road diesel engines worldwide to provide significant reductions in diesel particulate matter (PM) and oxides of nitrogen (NOx) emissions, as well as reductions in hydrocarbon (including toxic hydrocarbons like poly-aromatic hydrocarbons) and carbon monoxide (CO) emissions. There is already growing experience with these "clean diesel" emission control technologies on locomotive diesel engines. These locomotive engine applications pose unique operating environments and challenging packaging envelopes for emission control technologies, but over the past 30 years our industry has accepted and met every challenge in the design and optimization of emission control systems used on mobile source engines that range from small handheld equipment to large off-road equipment.

MECA strongly believes that many of the emission control technologies and strategies that are already in commercial use for light-duty and heavy-duty diesel vehicles meeting Environment Canada's 2004 On-Road Vehicle and Engine Emission Regulations, and under development to meet Environment Canada's 2005 Off-Road Compression Ignition Engine Emission Regulations will be applicable to locomotive diesel engines in the 2015 timeframe to meet U.S. EPA's Tier 4 locomotive emission standards and the locomotive regulations being proposed by Transport Canada.

MECA supported U.S. EPA's regulatory development of their Tier 4 locomotive emission standards and continues to believe that the technical analysis for the use of catalyst-based PM and NOx controls to achieve the Tier 4 standards for locomotive diesel engines is strongly supported by available data and experience with catalyst-based exhaust emission controls from the automotive, truck, locomotive, and marine industries. MECA strongly supports Transport Canada's proposal to align their locomotive emission regulations with the emission limits and compliance dates of U.S. EPA's Tier 3 and 4 standards for locomotive diesel engines because they are technically feasible.

Emission Control Technologies for Locomotive Diesel Engines

MECA would like to provide specific comments on the experience base with diesel particulate filters, diesel oxidation catalysts, and SCR catalysts since these emission control technologies were cited by EPA in their NPRM regulatory impact analysis for their potential in achieving the U.S. Tier 4 locomotive diesel standards.

Diesel Particulate Filters (DPFs) – Diesel particulate filters are commercially available today, with over 250,000 on-road heavy-duty vehicles worldwide retrofitted with high-efficiency DPFs and millions of new diesel passenger cars in Europe equipped with this technology since 2000. Since 2007 in the U.S. and Canada, all new heavy-duty diesel highway engines have been equipped with diesel particulate filters to achieve EPA's 2007 and Environment Canada's 0.01 g/bhp-hr PM highway diesel standard. New "clean diesel" light-duty vehicles that entered the U.S. and Canadian market last year are equipped with DPFs to achieve compliance with EPA's and Environment Canada's light-duty PM emission regulations.

To date, the real-world experience with DPFs in these light-duty and heavy-duty on-road vehicle applications has been very good. Through millions of miles of operation, DPFs continue to provide high reductions in PM emissions in these applications with very few operational problems with DPFs. Some problems reported by fleet owners having to do with regeneration of catalyst-based filters in the U.S. and Canada on 2007 model year and newer heavy-duty highway engines have been found to be related to software issues that are being remedied on second generation technology designs.

These on-road DPF applications are generally employing durable ceramic wall-flow filters to achieve in excess of 90% reduction in engine-out PM levels over years of operation. Light-duty and heavy-duty new vehicle applications of DPFs rely on combinations of both passive and active regeneration strategies for periodic combustion of soot that accumulates on the filter. In many cases, catalysts displayed directly on the filter substrate and/or located upstream of the filter element have been used to facilitate soot oxidation under normal exhaust temperatures. Similar to the highway and off-road diesel application areas, the U.S. EPA and Environment Canada have already put regulations in place requiring the use of ultra-low sulfur diesel fuel in locomotive diesel engines (starting in 2012), an important enabler for the use of catalyst-based PM control technologies. These wall-flow ceramic filter elements are now available in a number of material types including cordierite, silicon carbide, aluminum titanate, and mullite. Substrate manufacturers continue to refine the designs and production processes for these filter elements in order to improve durability characteristics, minimize exhaust backpressure, and make these filter substrates more compatible with catalyst coatings.

Wall-flow filters in addition to trapping soot also trap inorganic ash constituents present in the exhaust stream, chiefly associated with lubricant additive packages. Regular maintenance of wall-flow filters to remove accumulated ash is necessary to keep engine backpressures at acceptable levels. However, through the use of low-ash containing lubricants, improved engine designs that minimize lubricant consumption, proper filter substrate sizing, and novel filter substrate cell designs (e.g., asymmetric inlet and outlet cell sizes), ash cleaning intervals can be extended to many thousands of hours of operation. Some engine manufacturers have reported maintenance intervals for filters equipped on 2007 and later model year heavy-duty trucks to reach 300,000 miles or more in Class 8 long haul applications. MECA published a report on filter maintenance practices and experience in 2005. This report is available on the MECA website at: www.meca.org/galleries/default-file/Filter_Maintenance_White_Paper_605_final.pdf.

In the nonroad diesel engine application area, DPFs have been successfully installed and used on thousands of mining, construction, and materials handling equipment where vehicle integration has been challenging. Particulate filters, many employing active regeneration strategies such as fuel burners or electrical resistance heaters, have also been used on over 200 locomotives in Europe since the mid-1990s, providing in excess of an 85 percent reduction in particulate matter emissions. Some of these systems have been operating effectively for over 650,000 kilometers. A number of manufacturers are introducing new off-road vehicles equipped with DPFs to comply with U.S. EPA/Environment Canada interim Tier 4 PM emission standards.

Several demonstration projects have been, or are being conducted in the U.S., to evaluate the feasibility of equipping locomotive engines with DPFs. Active DPF systems, similar to those equipped on European locomotives, have been retrofit on two 1500 hp switcher locomotives. These two switchers are now operating in rail yards in southern California as part of an industry demonstration program. In another California demonstration project, DPFs will be demonstrated on two commuter rail locomotives operating between Oakland and Sacramento. Additional details of locomotive applications of DPFs are summarized in MECA's Locomotive and Marine case study report available at: www.meca.org/galleries/default-file/MECA%20locomotive%20and%20marine%20case%20study%20report%201006.pdf. ARB has also held Technical Symposia in 2006, 2007 and 2009 that detail the experience with DPFs on locomotives. Presentation slides shown at these ARB workshops are available at: www.arb.ca.gov/msprog/offroad/loco/loco.htm.

More recently, metal substrate filter designs have been developed and introduced for PM control of diesel engines. These designs combine more tortuous flow paths with sintered metal filter elements to achieve intermediate PM filtering efficiencies that can range from 30 to 70% depending on engine operating conditions and the soluble content of the diesel particulate matter emitted by the engine. Like ceramic wall-flow filters, these metal filter designs can be catalyzed directly or used with an upstream catalyst to facilitate regeneration of soot captured by the substrate. These metal substrate filter designs have been successfully used as a PM retrofit technology on a range of highway diesel engines. They have been used by one engine manufacturer (MAN) in Europe for complying with Euro 4 heavy-duty diesel PM limits, and are available in Europe as a retrofit PM technology for light-duty diesel vehicles. This metal substrate filter design has been used by Daimler on their Smart diesel passenger car in Europe to reduce PM emissions and comply with Euro 4 light-duty emission standards. Due to their more open designs, these metal substrate filters can operate over very long timeframes without the need for cleaning the substrate of trapped lubricant oil ash.

Diesel Oxidation Catalysts (DOCs) – DOCs are a well proven technology for oxidizing gaseous pollutants and toxic hydrocarbon species present in the exhaust of diesel engines. DOCs are also effective at reducing diesel PM emissions through the catalytic oxidation of soluble hydrocarbon species that are adsorbed on soot particles formed during the combustion process. DOCs can also oxidize NO present in the engine exhaust to NO_2. This NO_2 can then be used to oxidize soot captured on a DPF at relatively low exhaust temperatures (so-called passive filter regeneration) or to improve the low temperature performance of SCR catalysts by providing a more kinetically viable mixture of NO and NO_2 to the SCR catalyst. Both the oxidation of soluble PM species and NO oxidation pathways are useful in meeting the future locomotive regulations.

Over two million oxidation catalysts have been installed on new heavy-duty highway trucks since 1994 in the U.S. and Canada. These systems have operated trouble free for millions of miles. Most 2007-compliant heavy-duty trucks offered for sale in the U.S. and Canada include an oxidation catalyst upstream of a catalyzed diesel particulate filter in order to reduce PM emissions to levels below 0.01 g/bhp-hr. Oxidation catalysts have been used on millions of diesel passenger cars in Europe since the early 1990s and oxidation catalysts have been installed on over 250,000 off-road vehicles around the world for over 30 years. DOCs include Pt or Pt/Pd catalyst formulations supported on ceramic or metallic substrates.

Selective Catalytic Reduction (SCR) Technology – SCR technology is a proven NOx control strategy. SCR has been used to control NOx emissions from stationary sources for over 20 years. More recently, SCR systems have been applied to mobile sources, including trucks, off-road equipment, and marine vessels. Applying SCR to diesel-powered engines provides simultaneous reductions of NOx, PM, and HC emissions. Open loop SCR systems can reduce NOx emissions from 75 to 90 percent. Closed loop systems on stationary engines have achieved NOx reductions of greater than 95 percent. Modern SCR systems began to be installed on new 2010 model year light-duty and heavy-duty trucks last year. These systems combine highly controlled reductant injection hardware, flow mixing devices for effective distribution of the reductant across the available catalyst cross-section, durable SCR catalyst formulations, and ammonia slip clean-up catalysts that are capable of achieving and maintaining high NOx conversion efficiencies with extremely low levels of exhaust outlet ammonia concentrations over thousands of hours of operation. Furthermore, the use of downstream NOx reduction technology has provided engine manufacturers with additional calibration flexibilities that has resulted in significant fuel savings. Reports thus far claim to achieve a 5% fuel consumption reduction on long-haul heavy-duty application providing a rapid payback of the technology cost. This fuel economy benefit further results in a reduction of greenhouse gas emissions.

The majority of heavy-duty engine manufacturers are offering urea-SCR systems in highway truck applications to comply with Euro IV and V emission regulations in Europe, with more than 800,000 of these European SCR-equipped trucks already in service. All but one engine manufacturers in North America have decided to use combined DPF+SCR system designs for complying with EPA's 2010 heavy-duty highway emission standards and Canada's On-Road Vehicle and Engine Emission Regulations. DOC+SCR systems are also being used commercially in Japan by several engine manufacturers to comply with Japan's 2005 standards for new diesel trucks. DOC + SCR systems are being introduced on some new off-road diesel engines to comply with U.S. EPA/Environment Canada interim Tier 4 emission regulations. Several technology providers are developing and verifying retrofit SCR systems for both on-road trucks, off-road equipment and locomotives that combine SCR catalysts with either DOCs or DPFs.

SCR catalysts formulations based on vanadia-titania and base metal-containing zeolites have been commercialized for both stationary and mobile source applications. The maximum NOx conversion window for SCR catalysts is a function of catalyst and exhaust gas NOx composition. Base metal zeolite SCR catalysts, have been selected for applications that require NOx performance and durability under higher exhaust operating temperatures that may be encountered in some mobile source applications that combine a DPF upstream of an SCR catalyst (as would likely be the case for locomotive engines to comply with EPA's Tier 4 standards). To address tight packaging constraints and rapid heat-up requirements for low cold-start emissions, manufactures are developing durable SCR formulations that can be deposited directly on DPF filter substrates eliminating the need for a second catalyst device in the exhaust system. This has been shown to achieve equivalent NOx reductions with no negative impact on backpressure (SAE 2009-01-0910).

Base metal zeolite SCR catalysts have been commercially applied to stationary power generation applications since the mid-1990s. One MECA member has supplied zeolite-based SCR catalysts into a number of power generation applications. Included in this experience are examples of zeolite-based SCR catalysts that have operated in these stationary power generation applications for six years or more (more than 25,000 hours of operation) without catalyst replacement and delivered NOx conversion efficiencies in excess of 90%. This extended operation included SCR catalyst temperatures in excess of 540^{o}C through much of the six plus years of operation.

For low temperature NOx conversion efficiency, emission control system design engineers have a number of available options, including the composition of the SCR catalyst itself (e.g., Cu-zeolite SCR catalyst formulations typically have better low temperature performance than Fe-zeolite SCR catalyst formulations; e.g., see SAE paper no. 2007-01-1575), control of the ratio of NO_2 to NO present at the inlet of the catalyst, and improving the urea decomposition process at low exhaust temperatures. The impact of NO_2/NO ratio on low temperature performance of a Fe-zeolite SCR catalyst has been documented in the open literature. Higher ratios of NO_2/NO at the inlet of this zeolite-based SCR catalyst significantly improve NOx conversion efficiency at inlet gas temperatures between 150 and 250^{o}C. An oxidation catalyst function upstream of the SCR catalyst (e.g., a DOC or catalyzed DPF) can be used to oxidize NO to NO_2 and improve low temperature SCR catalyst performance.

Other Diesel Emission Control Technology Comments

The continued development and commercialization of durable DOCs, DPFs, and SCR catalyst systems is an important focus of the emission control industry and their customers in the engine, equipment, and vehicle manufacturing industries. But the new “clean diesel” world of technologies also includes other options for catalyst-based controls for NOx. NOx adsorber catalysts are in commercial production on a number of light-duty and medium-duty diesel vehicles offered by Toyota, Hino, Mercedes, and Chrysler/Cummins. The use of NOx adsorber catalysts has been successfully demonstrated commercially by Volkswagen on 2008 model year and newer light-duty diesel vehicles in North America. More recently, manufacturers have described NOx-based catalyst systems that combine NOx adsorbers (LNT) with SCR catalysts to eliminate the need for a second reductant, like urea, on board the vehicle. A commercial example of these combined technology offerings include the BlueTec system currently available on the Mercedes E320 CDI diesel in the U.S. and Canada. In some of these combined NOx adsorber and SCR catalysts, the primary NOx control pathway is through the NOx adsorber catalyst with the SCR catalyst providing incremental NOx conversion with the help of ammonia produced by the NOx adsorber catalyst during oxygen deficient regeneration operations. This ammonia is stored on the SCR catalyst and reacts with NOx during normal lean operating modes. These combination NOx adsorber/SCR catalyst system designs can also employ catalytic fuel reformers (see for example SAE paper no. 2006-01-3552) to provide an effective reducing environment for regenerating or desulfating the NOx adsorber function present in the system. Other systems being commercialized combine a base metal HC-SCR, or lean NOx catalyst (LNC) as the primary NOx reduction strategy or in combination with an ammonia SCR catalyst. The stand alone HC-SCR uses an 85% ethanol blend (E85) as the reductant to acieve over 85% NOx reduction. The combined system relies on a silver-based LNC for the primary NOx reduction during lean operation and to generate the ammonia during rich periods that is used by the downstream SCR to achieve combined system NOx conversion over 90%.

The clean diesel technology thrust has also spawned a variety of new sensor technologies that can be used to help control catalyst-based emission control technologies like SCR catalysts or NOx adsorber catalysts or be used for diagnostic purposes to determine if these systems are operating within design constraints. Examples of sensor developments include NOx sensors, ammonia sensors, and urea quality sensors. NOx sensors and urea quality sensors are already seeing commercial application on vehicles in Europe and Japan. NOx sensors are commercially available from one MECA member and have been used on light-duty and heavy-duty vehicle applications to control NOx adsorber-based catalysts and SCR catalysts. This NOx sensor technology utilizes electrochemical oxygen cells to simultaneously determine oxygen and NOx concentrations in an exhaust stream. The current generation of NOx sensors produced by this manufacturer recently successfully completed a 6000-hour durability test on a heavy-duty diesel engine equipped with a DPF + urea SCR system. Details of this 6000-hour durability test are contained in SAE paper no. 2005-01-3793. This NOx sensor design currently has engine-aged accuracy for NOx concentrations in the 0-100 ppm range of +/- 15%. The manufacturer of this NOx sensor technology introduced a next generation sensor with +/- 10% aged accuracy in 2010 and is targeting further improvements by 2013 with a clearly defined development path. NOx sensors are also under development by other manufacturers for applications on both on-road and off-road diesel engines to control catalyst-based NOx emission control systems and to provide diagnostic information concerning the performance of these systems. MECA expects suitable NOx sensors to be available for use on locomotive diesel engines in time for compliance with these regulations.

Reviews of diesel engine and diesel emission control technologies are available through a series of SAE papers authored by Dr. Timothy Johnson of Corning Incorporated. These annual review papers provide a large number of technical paper references and summaries of the technology advancements that are rapidly changing the nature of diesel engines in on-road and off-road applications. The most recent reviews provided by Dr. Johnson can be found in SAE paper nos. 2010-01-03041 and 2009-01-0121. The diversity of technology developments included in these review papers speaks to the significant breadth and volume of activity aimed at clean diesel technologies, including advanced diesel emission control technologies of all types for reducing PM and NOx emissions.

Conclusion

MECA and its member companies firmly believe that high efficiency and durable diesel particulate filters and SCR catalysts that will be required to meet the EPA Tier 4 standards and Transport Canada's proposed Locomotive Emissions Regulations for locomotive diesel engines will be available in the 2015 timeframe. The key will be to employ a systems approach consisting of the further evolution of locomotive diesel engine designs, the use of advanced emission control technology, such as diesel particulate filters and SCR catalyst systems, the use of ultra-low sulfur diesel fuel, and low ash and sulfur-containing lubricants. MECA has reviewed Transport Canada's Issue Brief, *Rolling Towards a Cleaner Future: The Development of Canadian Locomotive Emissions Regulations* and agrees with the technical assessments. MECA member companies have begun working with locomotive engine manufacturers on understanding current diesel PM and NOx catalyst performance and durability levels, and to begin the application engineering process for future locomotive diesel exhaust emission control systems.

Our industry is convinced that advanced exhaust emission controls that have already begun to usher in the new generation of clean diesel engines used in cars and trucks in the U.S., Canada, Europe, and Japan will also allow for significant reductions in both NOx and diesel particulate emissions from locomotive diesel engines in the next decade.

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