WRITTEN STATEMENT
OF THE
MANUFACTURERS OF EMISSION CONTROLS ASSOCIATION
ON THE
U.S. ENVIRONMENTAL PROTECTION AGENCY'S
CONTROL OF EMISSIONS OF AIR POLUTION FROM NEW LOCOMOTIVE ENGINES AND NEW MARINE COMPRESSION-IGNITION ENGINES LESS THAN 30 LITERS PER CYLINDER
ADVANCED NOTICE OF PROPOSED RULEMAKING

August 30, 2004

MECA is pleased to provide testimony in support of EPA's Advanced Notice of Proposed Rulemaking (ANPRM) for the Control of Emissions of Air Pollution from New Locomotive Engines and New Marine Compression-Ignition Engines Less Than 30 Liters per Cylinder. MECA believes an opportunity exists to significantly reduce emissions from new locomotive engines and new marine compression-ignition engines less than 30 liters per cylinder given adequate lead-time. At the public hearings conducted in 2003 for EPA's Tier 4 nonroad diesel engine standards, MECA stated that emissions from nonroad diesel engines can be significantly reduced by utilizing an engineered systems approach that incorporated and combined advanced engine designs, advanced emission control technology, and very low sulfur diesel fuel. MECA believes that this approach also can be applied to new locomotive engines and new marine compression-ignition engines less than 30 liters per cylinder to substantially reduce emissions from these engines. MECA believes that the general approaches recently used by the EPA to formulate emission reduction programs for highway heavy-duty diesel engines and nonroad diesel engines, requiring approximately 90% reductions in diesel particulate emissions and 90% reductions in NOx emissions versus engines certified without advanced emission control technologies, can be used as model for developing the next round of emission standards for new locomotive and marine diesel engines less than 30 liters per cylinder displacement. If the EPA's program is finalized, it will result in substantial, cost-effective emission reductions over the next several decades. Indeed, EPA's initiative will bring about the era of the truly clean new compression-ignition marine and locomotive engine.

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 engines used in nonroad applications. Several of our members have experience in successfully applying exhaust emission control technology to both marine diesel and locomotive applications. A 2004 survey of MECA's members revealed that our industry has invested over $1.8 billion in R&D and capital expenditures to develop, optimize, and commercialize advanced emission control technology to substantially reduce emissions from on-road and nonroad diesel engines. These same technologies can be used to substantially reduce emissions from marine and locomotive diesel engines.

TECHNOLOGICAL FEASIBILITY OF THE ANPRM FOR THE CONTROL OF AIR POLLUTION FROM NEW LOCOMOTIVE ENGINES AND NEW MARINE COMPRESSION-IGNITION ENGINES LESS THAN 30 LITERS PER CYLINDER

Overview

MECA believes that significant reductions of emissions from new compression-ignition marine engines with per cylinder displacement less than 30 liters and locomotive engines can be achieved in a cost-effective manner given adequate lead-time.

Technologies to reduce diesel emissions, such as diesel particulate filters (DPFs), diesel oxidation catalysts (DOCs), and selective catalytic reduction (SCR) systems, are commercially available today. These systems have been installed on vehicles and equipment both as original equipment and as retrofit technology on over 250,000 nonroad engines worldwide. Although not widespread, these technologies have been used commercially on marine and locomotive diesel engines. In fact, over 100 locomotives have been equipped with DPFs in Europe to reduce particulate emissions and over 100 marine vessels have been equipped with SCR systems for reducing NOx emissions. These technologies have also been equipped on a variety of large stationary diesel engines used for power production. The stationary diesel engine experience with emission control technologies such as DPFs, DOCs, and SCR is included in our comments since these applications have similarities to the design and operational characteristics of advanced emission systems expected with locomotive and large commercial marine diesel engines, such as large engine displacements requiring large volumes of emission control systems, significant steady-state operating time, and the integration of large emission control systems within the space constraints associated with the application.

Furthermore, MECA believes that the technologies and strategies being developed for the 2007/2010 heavy-duty highway diesel engine and Tier 4 nonroad diesel engine standards will be applicable to locomotives and marine engines. A comprehensive list of references discussing the considerable progress in developing, optimizing, and applying advanced emission control technologies and strategies for reducing emissions from diesel engines can be found in *Diesel Emission Control: 2001 in Review*, SAE Paper No. 2002-01-0285 (2002 SAE Congress, Detroit), *Diesel Emission Control: 2002 in Review*, SAE Paper No. 2003-01-0039 (2003 SAE Congress, Detroit) and *Diesel Emission Control Technology: 2003 in Review*, SAE Paper No. 2004-01-0070 (2004 SAE Congress, Detroit). Emission control technology options for nonroad diesel engines are also detailed in MECA's report "Exhaust Emission Controls Available to Reduce Emissions from Nonroad Diesel Engines" published in April 2003 and available on MECA's web site: www.meca.org.

PM, Toxic HC, NOx Emission Control Technology Capability and Experience

A number of advanced emission control technologies exist today to significantly reduce PM, HC, NOx, and toxic emissions from diesel engines that will also be available to substantially reduce emissions from marine and locomotive engines. These include DPFs, SCR, NOx adsorbers, lean NOx catalysts, EGR (exhaust gas recirculation), and DOCs. Crankcase emission control technologies will also be available to reduce crankcase emissions from these engines.

Diesel Particulate Filters (DPFs) – As noted above, DPFs are commercially available today. Over 150,000 on-road heavy-duty vehicles worldwide have been retrofit with DPFs and over 750,000 new diesel passenger cars in Europe have been equipped with this technology since 2000. At least two engine manufacturers are already offering diesel engines for transit applications integrated with DPFs, with all heavy-duty engine manufacturers intending to include integrated DPFs with all new U.S. highway heavy-duty diesel engines starting in 2007 (to meet EPA's 2007 highway heavy-duty engine particulate standard of 0.01 g/bhp-hr). Engine manufacturers have also begun to include DPFs with new heavy-duty diesel engines in Japan to comply with Japan's 2005 heavy-duty particulate matter standard. In all cases, these heavy-duty highway diesel engine applications in the U.S. and Japan will include active filter regeneration strategies to ensure that filter regeneration occurs under all engine operating conditions. In general, these active regeneration strategies for highway diesel engine applications include advanced engine controls and/or diesel fuel injection strategies that serve to elevate filter temperatures to levels necessary to ensure regeneration occurs on the vehicle.

For nonroad engines, DPFs have been successfully installed and used on mining, construction, and materials handling equipment where vehicle integration has been challenging. As EPA notes in the ANPRM, this may indeed be the case for locomotive and marine engines where our members' experience in the nonroad sector should prove beneficial. These nonroad applications include the use of both passive and active filter regeneration strategies. Active nonroad DPF options include diesel fuel injection strategies, engine throttling strategies, the use of electrical heating elements, and fuel burners.

Particulate filters, many employing active regeneration strategies such as fuel burners or electrical resistance heaters, have also been used on over 100 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. The European locomotive applications include DPFs installed on Caterpillar 3512 and 3516 engines powered at 1100 and 1500 kW, respectively. Currently, a DPF system is being installed on a 3000 kW diesel locomotive in Germany. Active DPF retrofit systems are also being evaluated in a railroad industry-sponsored test program at Southwest Research Institute (San Antonio, TX) using a two-stroke, V-16 locomotive engine rated at 1490 kW @ 900 rpm. Active DPF systems have also been used in Europe on a limited number of commercial marine diesel engines including sightseeing ships used on lakes in Switzerland.

Large stationary diesel engines used for both primary and back-up power generation have also been installed with DPF systems to control particulate emissions. Perhaps the most comprehensive information on the application of DPFs to stationary diesel engines can be found in the California Air Resources Board staff report issued in September 2003 to support ARB's air toxic control measure aimed at reducing particulate emissions from these engines (ARB staff report available at: www.arb.ca.gov/regact/statde/statde.htm). This report includes lists of DPF applications and reports on operating experience on large stationary engines in California. The California experience includes numerous DPF installations on large engines rated above 600 kW, including Caterpillar 3516 engines rated in the 1490-2120 kW range. Operating experience with these large engine DPF systems has been generally good with DPFs providing 85% or larger reductions in particulate matter compared to uncontrolled levels. Currently one manufacturer has been verified under ARB's diesel retrofit verification program with a DPF technology for stationary diesel engines. This DPF technology has been verified as a Level 3 technology (>85% particulate matter reduction) for a wide range of diesel engines used in stationary applications covering model year engines from 1996 through 2003. Additional verifications of retrofit DPF technologies for stationary engines are expected under this ARB program.

As part of their work on controlling particulate emissions from stationary diesel engines, ARB has conducted a test program to evaluate a number of emission control technology options on a stationary engine. Some discussion of this test program is also included in ARB's staff report referenced above. Options evaluated included a passive DPF approach and an active DPF approach utilizing electric resistance heaters. Both of these technologies were reported to reduce particulate emissions by more than 90% on a 2000 model year Caterpillar 3406C engine.

Where diesel fuel with <15 ppm sulfur is used, precious metal catalyst-based diesel particulate filters (CB-DPFs) have consistently demonstrated the capability to reduce PM emissions on a mass basis by up to 90 percent or more. In addition, this technology has proven effective in reducing the carbon-based PM by up to 99.9+ percent, while significantly reducing particle numbers over the full range of particle size, including ultra-fine particles. CB-DPF technology has also demonstrated the capability to reduce a wide range of toxic hydrocarbon species and PAHs by up to 80 percent or more.

Particulate filter systems are emerging that are specially designed to provide exhaust flow turbulence and increased particulate residence time, and have achieved PM reductions in the 40 to 65+ percent range. A version of this particulate filter technology is currently offered in Europe as a retrofit technology for reducing diesel particulate emissions from late model diesel passenger cars and being evaluated for heavy-duty diesel retrofit applications in the United States. A similar filter design is being evaluated for original equipment passenger car and heavy truck applications in Europe (see, e.g., *New Diesel Catalyst systems to Achieve European Legislation – Tested on a Volvo S60 Passenger Car*, 24th Vienna Motor Symposium, May 15-16, 2003, Vienna, Austria). Another design is being developed by a different manufacturer for nonroad engine applications, including engines under 37 kW.

Diesel Oxidation Catalysts (DOCs) – Over 250,000 nonroad vehicles and equipment, including mining vehicles, skid steer loaders, forklift trucks, construction vehicles, and stationary engines, as well as over 50,000,000 diesel passenger cars and over 1.5 million trucks and buses worldwide have been equipped with DOCs. Control efficiencies of 20-50 % for particulate matter (PM), up to 90 % reductions for CO and HC, including large reductions in toxic hydrocarbon species, have been achieved and reported in tests of DOCs on a large variety of on-road and nonroad diesel engines. With respect to particulate emissions, the wide range of PM reductions observed with DOCs reflects the fact that DOCs oxidize soluble hydrocarbons associated with PM (the so-called soluble oil fraction [SOF] of PM). The SOF content of PM is related in part to the oil consumption characteristics of diesel engines.

Although the application of DOCs to marine and locomotive engines is limited, the technology has been applied to some large, stationary diesel engines. An example of this is the installation of DOCs on an emergency generator in California in 2000. The engine is a Cummins KTA50-G9 rated at 1,650 kW. The DOC installed on this large diesel engine provides odor control as well as reductions in PM, CO, and hydrocarbon emissions. Several other DOC installations on stationary engines or tests of DOCs on stationary engines are listed in the ARB staff stationary engine report referenced previously in discussing DPF experience. Oxidation catalysts have also been installed on ferries operating around Hong Kong and have been effective in reducing particulate emissions.

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 15 years. More recently, it has been applied to select mobile sources including trucks, marine vessels, and locomotives. In 2005, SCR using a urea-based reductant is expected to be introduced on a large number of on-road diesel heavy-duty engines to help meet the Euro 4 heavy-duty NOx emission standards. Applying SCR to diesel-powered engines provides simultaneous reductions of NOx, PM, and HC emissions. Since the mid-1990s, SCR technology using a urea-based reductant has been installed on a variety of marine applications in Europe including ferries, cargo vessels, and tugboats with over 100 systems installed on engines ranging from approximately 450 to 10,400 kW. These marine SCR applications include the design and integration of systems on a vessel's main propulsion engines and auxiliary engines. A smaller number of SCR systems have also been installed on diesel locomotives, largely in Europe.

These SCR marine systems to date are responsible for emissions reductions of up to 99% for NOx, 90% or more for HC and CO, and reductions of PM up to 40% at the maximum vessel cruise rating. The systems also provide a 30-35 dB (A) noise reduction benefit in large marine engine applications. A typical urea consumption rate in a large commercial marine vessel can average 4-5 gallons per hour of a 40% urea/water mixture per megawatt of engine power. Marine SCR catalyst installations can add 30-60% to the weight and 20% to the volume of the normal muffler system used on these large marine engines. Typical SCR catalyst life in these marine applications can range from 10,000 to 40,000 hours.

Operating temperature windows for effective control of NOx in marine applications generally spans SCR catalyst temperatures in the 245-530^{o}C range. Recent work aimed at optimizing NO/NO_2 ratios entering the SCR catalyst for truck applications through the use of an upstream DOC that oxidizes engine-out NO to NO_2 has shown the ability to achieve NOx conversion efficiencies above 50% in the 200-250^{o}C range (see SAE Paper No. 2004-01-1289 by Walker et al.).

SCR has also been combined with DPF technology to provide simultaneous large reductions in NOx and PM emissions as well as reductions in CO and hydrocarbon emissions. In California, a 300-ton gantry crane powered by a turbocharged, after-cooled diesel engine rated at 850 kW was equipped with such a combined emission system in 2001. The expected emission reductions were an 85 % reduction of particulate matter and a 90 % reduction in NOx. A few combined SCR/DPF systems have also been installed on stationary diesel engines used for power production including six Caterpillar 3516B engines operating in southern California. Volvo AB recently announced in the summer of 2004 the launch of 27 diesel transit buses in Sweden that are operating with a combined SCR/DPF system to reduce PM and NOx emissions below the European Euro 5 heavy-duty emission limits that do not come into force until 2008. A number of small test fleets of heavy-duty over-the-road diesel vehicles are also operating within the U.S. to demonstrate the capabilities of combined PM and NOx control using SCR and DPFs. The U.S. Department of Energy's (DOE) APBF-DEC program includes the evaluation of two different combined SCR/DPF systems on a 12-liter heavy-duty diesel engine. Results on this program will be reported at the 10^{th} Annual DEER (Diesel Engine Emission Research) Conference during the week of August 29, 2004. The results to-date include the operation of these two different SCR/DPF systems for 2000 hours of durability with emission performance near the EPA 2010 heavy-duty on-road emission limits.

NOx Adsorber Technology – MECA believes that NOx absorber technology will also be an available NOx control strategy to help reduce NOx emissions form marine and locomotive diesel engines. NOx adsorber catalysts are currently being used commercially in light-duty gasoline direct injection (GDI) engines sold in Europe and Japan. This technology continues to undergo extensive research and development in preparation for the U.S. 2007/2010 on-road heavy-duty and Tier 4 nonroad diesel engine requirements. The progress in developing and optimizing this technology has been extremely impressive. Indeed, the Clean Diesel Independent Review Panel, charged by EPA to assess the technological progress in meeting the 2007/2010 standards, concluded in the latter part of 2002 that NOx adsorber technology development was on track to help meet the on-road heavy-duty engine standards and no technological roadblocks were identified. The recent EPA *Highway Diesel Progress Review Report 2* (March 2004) also summarizes recent results from the Department of Energy's APBF-DEC program that demonstrate the ability of a NOx adsorber/DPF system to maintain 90% NOx efficiency on a heavy-duty diesel engine for more than 1500 hours of operation. Information to be presented at DOE's DEER Conference will update information on this heavy-duty NOx adsorber/DPF system test program and show that this 90% NOx efficiency level was maintained through 2000 hours of durability including numerous high temperature desulfation events.

The current focus of NOx adsorber technology development and optimization is on: 1) expanding the operating temperature window in which the technology will perform, 2) improving the thermal durability of the technology, 3) improving the desulfurization methods and performance, and 4) improving system packaging and integration. The progress being made in these areas continues to be impressive. In light-duty applications, several automobile manufacturers are conducting in-vehicle tests with NOx adsorber/DPF systems (see, for example, SAE Paper No. 2004-01-1791 for EPA's emission tests of prototype vehicles equipped with NOx adsorber/DPF systems) and one manufacturer introduced a diesel-powered passenger car in Europe and a diesel-powered light-duty truck in Japan with a combined NOx adsorber/DPF system in late 2003.

Low-Pressure EGR – This technology is being successfully demonstrated in retrofit applications on trucks, buses, and other applications. Over 1500 systems are running worldwide. Low-pressure EGR has demonstrated a NOx control capability in the range of 30 to 60 percent. With an active DPF and <15 ppm sulfur diesel, NOx control levels as high as 80 percent may be achievable. Current experience with low-pressure EGR is in the 140-330 kW range, with a new larger EGR valve now being offered to cover diesel engine applications up to 750 kW. Low-pressure EGR systems are currently being developed for stationary diesel engines rated at up to 2200 kW.

Lean NOx Catalyst (LNC) Technology – This technology, which has been utilized in passenger car applications in Europe, recently was verified by the California Air Resources Board (25 percent NOx control) in retrofit applications. This technology, which is being used in combination with both DPFs or DOCs, is being demonstrated and commercialized for a variety of nonroad applications, including heavy-duty earthmoving equipment, agricultural pumps, and portable engines, and can also be used to reduce emissions from marine and locomotive diesel engines.

Crankcase Emission Controls – Crankcase emissions from diesel engines can be significant and can be controlled by the use of a multi-stage filter designed to collect, coalesce, and return the emitted lube oil to the engine's sump. Filtered gases are returned to the intake system, balancing the differential pressures involved. Typical systems consist of a filter housing, a pressure regulator, a pressure relief valve, and an oil check valve. These systems have the capability to virtually eliminate crankcase emissions. This technology is currently being used in Europe on new engines as well as the United States on a retrofit basis. Closed crankcases with filtration systems will be required on new heavy-duty on-road and nonroad diesel engines as part of EPA's regulatory programs covering these applications.

SPECIFIC COMMENTS RELATED TO THE EMISSION STANDARDS BEING CONSIDERED FOR LOCOMOTIVE ENGINES AND MARINE COMPRESSION-IGNITION ENGINES LESS THAN 30 LITERS PER CYLINDER

MECA agrees with EPA that identifying available space on locomotives and marine diesel engines to equip the emission control technology is a challenge. However, we believe that this challenge can be overcome. Our members have over 25 years experience in applying emission control technologies to a wide variety of vehicles and equipment. MECA members already have experience in fitting emission control technology to locomotive and marine applications as noted above. MECA members also have experience in equipping very large engines used in power generation with emission control technology. In all of these examples, emission systems had to be designed and integrated with these engines based on available space and operating requirements of the engine and the emission system. This experience, combined with advances in catalyst technology which may result in reduced catalysts volumes, will help locomotive manufacturers take advantage of the advanced technologies our members are producing and developing to significantly reduce emissions from both marine and locomotive diesel engines.

MECA concurs with EPA that it may be necessary for advanced exhaust emission controls in at least some locomotive and marine applications to use active regeneration mechanisms, such as the post-injection of diesel fuel into the exhaust stream to initiate thermal transients, fuel burners, and/or electric heaters. We believe that the advances being made with these active strategies and technologies for the 2007/2010 on highway and Tier 4 nonroad rules will be applicable to marine and locomotive applications.

For recreational marine applications or other applications where the exhaust is mixed with water, MECA agrees that it may be necessary to redesign exhaust systems to ensure there is enough room in the dry part of the exhaust system to package the emission control system. Work at Southwest Research Institute sponsored by the California Air Resources Board and the

National Marine Manufacturers Association on recreational spark-ignited marine engines (sterndrive or inboard, automotive-type engines) has successfully developed exhaust systems that incorporate three-way catalysts into the exhaust systems of these engines. Similar packaging strategies may be necessary on recreational marine diesel engines.

History has shown that advanced emission control technologies have been applied to a wide variety of mobile source applications in a cost-effective manner. Indeed the cost of meeting new, stricter emission requirements has always been less than initially anticipated. We believe that new strict emission standards for marine and locomotive diesel engines will also be met in a cost-effective manner given adequate lead-time.

Earlier this year MECA published a survey of projected costs for a variety of catalyst technologies that are anticipated to be used to control PM and NOx emissions from highway heavy-duty diesel engines covering engines with six liters, eight liters, and 13 liters in total displacement. The survey assumed high volume production rates and included costs to engine manufacturers for DOCs, DPFs, SCR catalysts, and NOx adsorber catalysts (catalyst-coated substrate costs only, no packaging costs). For the largest highway engine, the survey projected costs were $354.00 for a DOC, $1050.00 for a catalyst-based DPF, $319.00 for an SCR catalyst, and $1354.00 for a NOx adsorber catalyst. These costs were generally in-line with technology costs reported by the EPA as a part of their 2007-2010 highway heavy-duty emission program or their Tier 4 nonroad emission program. These costs are included here for reference; however, extrapolating these technology costs for high sales volume highway diesel engines to low sales volume, very large marine and locomotive engines is not appropriate. A few references to technology costs for large stationary engines and commercial marine engines are available.

ARB in their stationary engine staff report referenced previously estimated costs for a DPF on a stationary diesel engine rated at 440 kW to be $22,400.00 for equipment and installation (approximately $50/kW). DOC costs for a similarly sized stationary engine were estimated to be $6150.00 (about $14/kW). In a July 2002 report, a CALSTART study sponsored by DOE, the Gas Technology Institute, and the Department of Transportation (DOT) evaluated various options for reducing emissions form passenger ferries operating in the San Francisco Bay area. Included in these options were equipping EPA Tier 2 compliant engines with a catalyst-based DPF, with SCR, and with a combined SCR/DPF system (DPF operating at 90% PM reduction efficiency, SCR operating at 80% NOx reduction efficiency). Estimated emission system option installed costs from this study were $20/kW for the DPF option, $71/kW for the SCR option, and $91/kW for the combined SCR/DPF option. Current large-scale commercial marine SCR-only applications in Europe are in the $22-$45/kW range. Installed emission control technology costs for future marine diesel or locomotive engines will be strongly influenced by engine-out emission levels of these future standards relative to the target operating efficiencies required to meet future emission standards. Future locomotive and marine engine designs would be expected to take advantage of the many improvements in diesel engine fuel injection, air handling, and combustion technologies that are now focused on on-road diesel engines to reduce engine-out emissions.

MECA believes that any new standards for marine and locomotive diesel engines should apply to the widest possible engine operating conditions to ensure maximum emission reductions. We also believe that many of the on-board diagnostic strategies being developed for highway diesel engines will be applicable to nonroad diesel engines including the marine and locomotive engine categories.

CONCLUSION

While we recognize that the standards being considered by EPA present engineering challenges, we also believe these challenges can and will be met. Our industry has successfully provided cost-effective emissions control technologies for over 25 years. We look forward to working with EPA, the engine and equipment manufacturers, the end users, and others as the Agency moves forward in considering new emission standards for marine and locomotive applications. Our industry is committed to do its part to ensure that the new locomotive and marine engine standards being considered will be able to have the desired emission reductions needed at a reasonable cost, with very good performance over the required useful life and optimized operating characteristics that minimize impacts on engine fuel consumption.