Summary and Analysis of Comments: Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression Ignition Engines Less than 30 Liters Per Cylinder

Chapter 10
Technical Feasibility

Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

United States
Environmental Protection
Agency

EPA420-R-08-006
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10. TECHNOLOGICAL FEASIBILITY

What We Proposed:

The comments in this section relate to the technological feasibility of the standards described in Section III of the preamble to the proposed rule and Chapter 4 of the Draft Regulatory Impact Analysis (Draft RIA, or DRIA). Note that this chapter addresses only the specific comments we received. See Chapter 4 of the Final RIA for a more complete feasibility analysis.

10.1 Remanufactured Locomotive Standards

10.1.1 Lead-Time for Tier 2 Remanufactured Locomotive

What Commenters Said:

The Engine Manufacturers Association (EMA) commented that the requirement for Tier 2 locomotives originally manufactured between 2005 and 2012 to meet a modified Tier 2 particulate matter (PM) level of 0.1 grams per brake horsepower-hour (g/bhp-hr) when remanufactured effectively sets a standard without any lead time. The commenter raised the concern that customers for current-design Tier 2 engines will expect immediate answers for how the new Tier 2 standards will be met when their engines are remanufactured after 2013, and further that those expectations for compliance with the new Tier 2 standards will be occasioned by the Notice of Proposed Rulemaking (NPRM), even before the final rule is issued. EMA commented that before finalizing the Tier 2 standard for remanufactured locomotive engines, it believes that EPA must consider the lack of lead time associated with the standard and the potential impact on future sales of Tier 2 locomotive engines.

The Natural Resources Defense Council (NRDC) also commented that EPA should strengthen the program to clean up existing engines by requiring existing train engines to be cleaner when they are rebuilt, as soon as possible and no later than 2010 for any locomotive engine (versus waiting until 2013 to make the clean-up of all existing locomotive engines mandatory, as proposed in the NPRM). NRDC also cited Wall Street Journal comments made by EMD in which it stated that "…we're definitely intending to meet all of the [EPA] rules and requirements." NRDC commented that EMD's statement shows that the proposed standards and timetables are feasible.

Letters:

Engine Manufacturers Association (EMA)	OAR-2003-0190-0575.1
Natural Resources Defense Council (NRDC)	OAR-2003-0190-0489

Our Response:

We have set the Tier 2 locomotive remanufacturing standard, commented on here by EMA, and the new Tier 3 locomotive standard at the same level with the intent that both standards can be met using the same technology solutions (and concurrent technology development plans). Specifically, we project manufacturers will use incremental improvements to engine hardware to reduce oil consumption, possible changes in fuel system hardware or parameters to reduce soot formation, and other engine-out PM emission control technologies as described in chapter 4 of the Final RIA. Considering the incremental nature of these changes and the availability of ultra-low sulfur diesel fuel (ULSD) in 2012, there is sufficient lead time (at least five years) for manufacturers to develop Tier 2 remanufactured engine solutions to meet the new emission standards. Please refer to Chapter 4 of the RIA for a further description of the engine technologies that are expected to be used to meet the Tier 3 and remanufactured Tier 2 locomotive emission standards. NRDC called for acceleration of the Tier 2+ remanufactured engine standard, by as much as 3 years, but did not provide evidence that this would be feasible. Our own analysis, discussed in RIA section 4.2 and in the rulemaking preamble section III.C, leads us to conclude that a year of lead time after the 2012 Tier 3 start date is appropriate to adapt Tier 3 technologies to the Tier 2+ locomotive remanufacture systems, and that 2012 is the appropriate start date for Tier 3. Our early introduction provision requiring use of any Tier 2+ systems certified before 2013 provides incentive for early introduction without risking disruption of the long-term program from overly aggressive mandatory short-term objectives. We also note that very early certification of Tier 2+ systems, either on a mandatory or voluntary basis, would not likely have a large environmental impact because the Tier 2 fleet is still quite new and not likely to be coming due for first remanufactures for some time yet.

10.1.2 Stringency of Remanufactured Locomotive Standards

10.1.2.1 Tier 2 PM for Remanufactured Locomotive

What Commenters Said:

As discussed in Chapter 3 of this Summary and Analysis of Comments document, EMA commented that the proposed Tier 3 PM reductions represent a 50% reduction from the current Tier 2 locomotive PM standards while the relevant Tier 2/Tier 3 PM standard for nonroad engines is only a 35% reduction. The commenter stated that it believes that those proposed standards are too aggressive, since, among other things, they are substantially lower than the Tier 2 and Tier 3 nonroad PM standards. The commenter urged EPA to consider a less aggressive step in PM reduction over the current locomotive standard, and suggested that a 35% reduction is a more reasonable reduction for the Tier 2/Tier 3 PM standards, and is more in line with the nonroad engine PM emission standards.

<u>Letters:</u>

Engine Manufacturers Association (EMA) OAR-2003-0190-0575.1

Our Response:

The commenter correctly notes that we have set a more stringent Tier 3 PM standard than the Tier 2/3 nonroad PM standard set almost ten years ago. The more stringent PM standard, a 50% reduction in PM emissions from the current locomotive Tier 2 standards to the new locomotive Tier 3 standards reflects the advanced state of diesel engine technology and reflects a technologically feasible and cost effective means of reducing PM emissions from locomotives. The commenter did not state that a 50% PM reduction was not feasible for locomotives. Further, nonroad generators over 560 kW have already been introduced with PM emissions certified under 0.10 g/bhp-hr on the 5-mode D2 test cycle (2007 Cummins engine family 7CEXL050.AAD at generator ratings of 1300 kW and 1500 kW).

10.1.2.2 Tier 2 PM for Remanufactured Switchers

What Commenters Said:

As discussed above in Chapter 3 of this Summary and Analysis of Comments document, EMA noted that the proposed Tier 2 PM standards for rebuilt engines and the proposed Tier 3 PM standards for new switcher applications are at the same level. The commenter noted that those proposed levels are a similarly aggressive 50% reduction when compared to the current Tier 2 switcher standard, and that the proposed Tier 2 PM rebuild standards and the Tier 3 PM standards for new switcher applications are not in harmony with the nonroad Tier 2 and Tier 3 PM standards, and so will require new engine development programs outside of the scope of what is in place for nonroad engines. The commenter suggested that, to avoid the unacceptable workload burden that would result for engine manufacturers, and to attain proper alignment with the nonroad engine standards, the Tier 2 switcher rebuild standard should be set at 0.15 g/hp-hr (0.20 g/kW-hr) instead of 0.13 g/hp-hr (0.17 g/kW-hr) PM, and the Tier 3 new switcher standard should be set at 0.15 g/hp-hr (0.20 g/kW-hr) instead of 0.10 g/hp-hr (0.13 g/kW-hr) PM. EMA commented that it believes that unless there is this type of harmonization of the PM standards, the otherwise slight differences in the two sets of PM standards will drive separate technologies or engine families, which is simply unacceptable for engine manufacturers. The commenter further stated that it believes that the impact on the proposed PM standards from the recommended harmonization is small, and it is still a greater percent reduction in PM emissions than what has been proposed for the line-haul application.

Letters:
Engine Manufacturers Association (EMA) OAR-2003-0190-0575.1

Our Response:

National Railway Equipment Co. (NREC) and Railpower Technologies, two of the largest switch locomotive manufacturers, have already introduced low-emission switch locomotives based on nonroad Tier 2 and Tier 3 engine technology. NREC switch locomotives based on nonroad Tier 3 technology have been introduced in the U.S. with PM emissions of 0.06 g/bhp-hr over the locomotive switch cycle, already 40% below the 0.10 g/bhp-hr Tier 3 switch locomotive PM standard. The Railpower Technologies RP20BD switch locomotives introduced in January 2006 use Deutz 2015 Tier 3 nonroad engines certified over the nonroad 8-mode test cycle at less than 0.04 g/bhp-hr. We do not believe that the Tier 3 and remanufactured Tier 2 switch locomotive standards represent an undue workload burden on nonroad Tier 3 engine suppliers because of the current availability of engine families suitable for switch locomotive applications with PM emissions that are well below 50% of the Tier 3 nonroad standard. Such engines are already offered for switch locomotive applications and already have PM emissions consistent with a switch locomotive standard of 0.10 g/bhp-hr.

10.1.2.3 NOx Control for Older Tier 0 Locomotives

What Commenters Said:

Electro-Motive Diesel, Inc. (EMD) commented that it believes that the Tier 1 standards for Part 92 Tier 0 locomotives are feasible, but it is concerned that one type of separate-loop aftercooled locomotives may be subject to loss of power at high temperatures if the oxides of nitrogen (NOx) standard is not revised. EMD calculates that, even with cooling system modifications, the model will be forced to derate at ambient temperatures above approximately 95 °F and at the maximum design temperature of 115 degrees, traction horsepower will have fallen from the rated 4000 to approximately 3150. The commenter noted that these locomotives are critical to the coal-hauling fleet of at least one major railroad, thus such a power loss represents a major loss of value. Further, the commenter urged EPA to discuss the format of the new Tier 1 standards with stakeholders before the final rule is issued.

General Electric Transportation (GE) commented that more than 2000 of its Tier 0 locomotives which were built without split cooling systems cannot meet the proposed 8.0 g/bhp-hr NOx standard. GE further commented that these locomotives would require substantial cooling system and engine system upgrades to meet the standard, and that the cost of these changes would exceed the $125,000 limit for incremental hardware cost.

The Association of American Railroads (AAR) commented that it believes that the Tier 0 standards are infeasible for some engines. The commenter noted that GE informed EPA and AAR that the proposed Tier 0 standards for all GE locomotives cannot be met without a separate intake air coolant loop. The commenter stated that, in this respect, EPA’s proposed rule is based on an assumption that is incorrect. The commenter cited the statement in the Notice of Proposed Rulemaking (NPRM) that for discussing locomotives built without a separate intake air coolant loop “[EPA’s] analysis indicates that it is feasible to obtain a NOx reduction for them on the order of 15 percent, from the current Tier 0 line-haul NOx standard of 9.5 g/bhp-hr to the proposed 8.0 g/bhp-hr standard.” The commenter noted that GE has stated that it cannot meet the 8.0 g/bhp-hr NOx standard or the 0.22 g/bhp-hr PM standard without a separate intake air coolant loop. AAR further noted that even retarded engine timing, ignoring the fuel and emissions impacts it would have, would not work because GE could not retard engine timing to the point where both the NOx and PM standards could be met. The commenter noted that it is generally agreed that retrofitting old locomotives with a separate intake air coolant loop is untenable, because the cost of remanufacturing would approach the value of the locomotive, making remanufacturing of these over twenty-year old locomotives uneconomical. AAR commented that it understands that, notwithstanding the approach set forth in the proposed rule, EPA intends to change the proposed rule so that retrofitting locomotives with a separate intake air coolant loop will not be required. The commenter urged EPA to make the railroads part of the discussion as to what standards would be appropriate for these locomotives due to the significant impact it could have on AAR members and the industry.

AAR also commented that it does not agree with the proposal to require all Tier 0 locomotives to be subject to more stringent emissions standards when remanufactured. The commenter noted that remanufacturing some of these older locomotives to more stringent standards might not be worth the expense, and as a result, railroads might continue to use these locomotives well past their regulatory useful lives, for as long as possible without remanufacturing, and then retire them upon failure. The commenter is concerned that these engines will not be moved to switch service or small railroad applications (as EPA posits), but rather the locomotives will continue to be used by Class I railroads to failure. (The commenter noted that the majority of the older Tier 0 engines in question are six-axle locomotives, which are ill suited for switch service and small railroad applications.) AAR thus stated that it believes that subjecting older Tier 0 locomotives to more stringent standards might be counterproductive from an environmental viewpoint; and that EPA should consider whether or not the environment will benefit from applying regulations to these locomotives that will provide an incentive to avoid remanufacturing to EPA standards.

Letters:

Association of American Railroads (AAR)	OAR-2003-0190-0566.1
Electro-Motive Diesel, Inc. (EMD)	OAR-2003-0190-0594.1
General Electric Transportation (GE)	OAR-2003-0190-0590.1

Our Response:

We have undertaken a comprehensive model-by-model review of the existing post 1972 locomotive fleet to understand the issue raised here and to ensure that the remanufacturing standards that we are finalizing will achieve the greatest degree of emission reduction achievable through the application of technology which the Administrator determines will be available for the engines or vehicles to which such standards apply, giving appropriate consideration to the cost of applying such technology within the period of time available to manufacturers and to noise, energy, and safety factors associated with the application of such technology. As the commenters note, some existing locomotive engines have inherent limitations set when they were first built, in some cases more than 30 years ago. We have therefore made specific changes to our proposed remanufacturing standards to ensure that the standards are achievable for these locomotives. In this case, we have defined some narrow emissions “carve outs” for a limited number of the existing locomotives that ensure we are achieving the maximum degree of emission reductions possible while reflecting the technological limitations of these existing locomotive designs. Please refer to 40 CFR 1033.655 for specific regulatory provisions regarding certain Tier 0/Tier 1 locomotives. This subject is also addressed in section 3.1.1.1.

10.2 Tier 3 and Tier 4 Locomotive Standards

10.2.1 Lead-Time for Tier 4 Locomotive Standards

What Commenters Said:

GE commented that, while it does not believe the 2017 compliance date should be accelerated, it believes that it is important to recognize that the environmental benefits of Tier 4 locomotives will be achieved for model years beginning in 2015 and that many locomotives will be operating in the Tier 4 configuration for test purposes well before the 2017 compliance date. (Note that GE also submitted a later supplemental comment stating that it would support a regulatory option in EPA's final rule that brought the Tier 4 NOx compliance date to 2015 provided the program included a significantly longer in-use add-on period to address their durability concerns).[1] The commenter suggested that it would be more technologically defensible for EPA to make the transition period consistent with the useful life of the locomotive (i.e., EPA should not impose the Tier 4 NOx standard until one useful life has passed after 2015). The commenter also suggested that EPA should also consider extending the number of model years for the deterioration add-ons for both Tier 4 NOx and particulate to cover a typical useful life period of seven model years.

GE also commented that it agrees that a phase-in period is needed given the significant technical challenges of installing NOx aftertreatment systems on locomotives. The commenter noted that the Manufacturers of Emission Controls Association’s (MECA) testimony at the Chicago public hearing indicated that the control manufacturers only anticipate having their systems ready for introduction in 2015. The commenter stated that this means EPA has only provided two years for integration into the locomotive and testing on the rails, which it believes demonstrates that an earlier introduction date is not achievable. The commenter further stated that it believes that the 2015 date suggested by MECA really needs to be 2012 for aftertreatment technology to be commercially available on the locomotive in 2017. GE commented that, during the 2010 catalyst technology review, EPA should consider whether the catalyst will be available in a time frame that allows integration and testing; the commenter believes that accelerating the 2017 compliance date is neither possible nor responsible given the need for reliability of

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[1] Email from Shannon Broome, General Electric, to Byron Bunker, U.S. EPA, Re: Supplemental Comment of General Electric - February 12, 2008

locomotives in service. The commenter noted that, manufacturers and railroads have told EPA before, reliability is paramount in railroad service. The commenter stated that, since NOx and PM aftertreatment is a major new technology application for locomotives, an intensive program of development and reliability demonstration, including two to three years of in-house development and a field test of at least two years, will be necessary before it is placed into full production.

EMD commented that, with regard to the staggered introduction of aftertreatment-forcing PM standards in 2015 and such NOx standards in 2017, it believes that EPA has properly phased-in aftertreatment on locomotives. The commenter noted that in the on-highway market aftertreatment-forcing PM standards took effect in 2007 with similar NOx standards fully effective in 2010, and a similar phasing-in has been instituted in the nonroad engine market. The commenter stated that with this, EPA has recognized the limitations of manufacturers in making large technological jumps all at once, and has served its own desire, which EMD supports, to address PM emissions more urgently than NOx. The commenter stated that it believes that such phasing is particularly important in the locomotive—and, incidentally, the Category 2 marine engine (most of which are derivatives of locomotive engines)—market, because locomotive manufacturers are relatively small companies with limited resources. EMD urged EPA to resist any requests for introduction of aftertreatment for both NOx and PM at the same time.

AAR commented that it does not believe that the Tier 4 standards could be effective earlier because there is no basis for believing the research and testing that needs to be done to meet those standards will be completed before the proposed effective dates. The commenter noted that the standards will require aftertreatment devices, diesel particulate filters (DPFs) for PM control, and selective catalytic reduction (SCR) systems for NOx control. The commenter stated that, in general, new technology must be field-tested for at least two years before it can be implemented on a widespread basis; and aftertreatment is such a major change that more than two years of field testing will likely be necessary. The commenter stated that it believes that it will be years before DPF and SCR systems for line-haul locomotives will be available for testing because there has been little research on aftertreatment systems for locomotives compared to research on highway vehicles, especially with respect to high horsepower line-haul locomotives. The commenter noted that over the last ten years, the average number of brand-new locomotives placed in service by U.S. freight railroads was 773. AAR commented that because the locomotive market is so small, and heavy-duty motor vehicles have a 2010 deadline by which they will need to be equipped with both DPF and SCR systems, the aftertreatment industry has focused its resources on developing systems for motor vehicles (not nonroad vehicles/equipment).

EMA commented that it believes that the fact that metal catalyzed diesel particulate filter (metal-CDPF) systems have not been demonstrated in large size applications should be recognized. The commenter noted that the required scale-up to large units is not trivial, and substantial lead time (several years) is needed to have units designed, built, and tested to have any certainty that they will function and survive in marine or locomotive applications. The commenter further noted that redesign to incorporate what is learned in the field also may be needed.

The Northeast States for Coordinated Air Use Management (NESCAUM) encouraged EPA to require Tier 4 emissions levels for both NOx and PM by no later than the end of 2013, rather than the respective proposed dates of 2017 and 2015.

The National Association of Clean Air Agencies (NACAA) recommended that the implementation dates for new engine and remanufacture standards be accelerated. The commenter noted that technical experts within NACAA (including those from the California Air Resources Board (CARB) and the South Coast Air Quality Management District (SCAQMD)) believe that Tier 4 NOx and PM standards for new engines at least as stringent as those proposed are technologically feasible by the end of 2013. NACAA recommended that EPA advance the rule's implementation dates accordingly.

The New Jersey Department of Environmental Protection (NJDEP) recommended that the proposed locomotive emission standards implementation schedule be accelerated, based on the rationale outlined by NESCAUM and NACAA. The commenter said that the Tier 4 emission standard implementation schedule should be shortened. NJDEP expressed support for the proposed Tier 4 1.3 g/bhp-hr NOx emissions standard and 0.03 g/bhp-hr PM standard for new locomotives by the end of 2013, rather than 2017 and 2015, respectively. NJDEP commented that most of EPA's rationale for the proposed standards timetable is due to current technology and future technology assumptions. The commenter noted that it hired an expert in the field of diesel emission reduction technology; this expert developed a report (OAR-2003-0190-0562.3) which demonstrates that the technology is far enough along to support an accelerated timetable.

The Missouri Department of Natural Resources (MDNR) recommended shortening the time period until the implementation of both the new engine emission standards and remanufactured engine emission standards for locomotives. The commenter requested that the standards be implemented as soon as they are technically feasible to allow for emissions reductions as soon as possible.

The Puget Sound Clean Air Agency commented that the rule can be improved significantly by advancing the dates on which new and remanufactured engine standards are implemented.

The Wisconsin Department of Natural Resources (WDNR) requested that EPA accelerate the implementation dates for emission standards for new and remanufactured locomotives.

The Ozone Transport Commission (OTC) commented that its member states encourage EPA to examine the effective dates for many of the standards proposed. The commenter recommended that EPA finalize a 2013 deadline for the proposed Tier 4 locomotive standards.

The South Coast Air Quality Management District (SCAQMD) commented that, based on its own research and commercialization efforts on advanced emission control technologies and deployment of cleaner alternative fuels and diesel fuel alternatives under the SCAQMD Clean Fuels Program, the proposed compliance schedules can be substantially accelerated. SCAQMD commented that it strongly urges EPA to move up the proposed Tier 4 standard for new locomotive engines to June 2012 (at the latest), when ULSD will be required for locomotives. The commenter noted that the proposed dates for new locomotive Tier 4 PM engine standards fall in the deadline year for the South Coast region and the San Joaquin Valley to meet the federal annual PM2.5 air quality standard. The commenter stated that the proposed deadline is too late to provide any assistance in meeting the federal annual PM2.5 standard, given that the proposed advanced control standards for locomotives only apply to new units and the resulting need to allow time for fleet turnover before benefits are realized. The commenter further suggested that the implementation date for the Tier 3 standards be moved to the end of 2010.

SCAQMD commented that it agrees with EPA's statement that the Tier 4 locomotive standards are feasible using today's technology, and stated that there is no need to delay implementation of these standards to await development of technology. The commenter noted that the Clean Air Act (CAA) (at section 213(b)) requires EPA to adopt standards which "take effect at the earliest possible date", thus the commenter stated that Tier 4 technology must be required as quickly as manufacturers can gear up to produce it.

SCAQMD commented that its staff has been in discussion with CARB staff on a proposal that could deploy Tier 4 locomotives by 2010. The commenter stated that the proposal is based upon the use of multiple off-road engines in conjunction with DPFs and SCR to achieve or exceed the proposed Tier 4 emission standards. SCAQMD commented that it views this proposal as particularly promising because it relies on existing, commercially available engines, and because such multiple engine configurations have been successfully utilized to create lower emission switch locomotives. The commenter stated that it believes that there is no technical reason why such engines and configuration should not be able to achieve a Tier 4 line-haul locomotive in a timeframe enormously accelerated from EPA's proposed regulation. (The commenter noted that a copy of the presentation from NREC and Cummins attached to its public comments.)

The City of Houston, Bureau of Air Quality Control (BAQC) requested that EPA require compliance with the Tier 4 PM, HC, and NOx emissions standards by no later than June 2012 because it is achievable.

Letters:
Association of American Railroads (AAR) OAR-2003-0190-0566.1
City of Houston, Bureau of Air Quality Control (BAQC) OAR-2003-0190-0561.1
Electro-Motive Diesel, Inc. (EMD) OAR-2003-0190-0594.1
Engine Manufacturers Association (EMA) OAR-2003-0190-0545
General Electric Transportation (GE) OAR-2003-0190-0590.1
Manufacturers of Emission Controls Association (MECA) OAR-2003-0190-572.1

Missouri Department of Natural Resources (MDNR)	OAR-2003-0190-0658
National Association of Clean Air Agencies (NACAA)	OAR-2003-0190-0495
New Jersey Department of Environmental Protection (NJDEP)	OAR-2003-0190-0562.2
Northeast States for Coordinated Air Use Management (NESCAUM)	OAR-2003-0190-0551.1
Ozone Transport Commission (OTC)	OAR-2003-0190-0633.1
Puget Sound Clean Air Agency	OAR-2003-0190-0484
South Coast Air Quality Management District (SCAQMD)	OAR-2003-0190-0483, 0558.1
Wisconsin Department of Natural Resources (WDNR)	OAR-2003-0190-0552

Our Response:

Many of the comments summarized here reflect the general concern that much of the rail industry has felt regarding the introduction of advanced PM and NOx control technologies in our proposed Tier 4 program. Unlike the marine sector - where high-speed marine engine manufacturers have significant experience with advanced control technologies for their on-highway and nonroad products - locomotive manufacturers do not have this experience and have therefore been more cautious in accepting such significant new technologies. To address their concerns, we engaged in extensive outreach with the rail industry (including all of the commenters here) to ensure that they fully understood our expectations for what the proposed Tier 4 locomotive program would mean. Included in that outreach was cooperative testing to evaluate in-use conditions expected of locomotives operating in high altitude tunnels and our own testing at the National Vehicle and Fuel Emissions Laboratory to demonstrate the emission results that would be expected of a Tier 4 locomotive engine design. The result of all of this work is reflected in our Final RIA and in memorandums to this rulemaking docket.

As an outgrowth of the comments summarized here and the results of our analyses, outreach and test programs, we have made some important changes in our final rulemaking. In particular, we agree with commenter GE that it may be more appropriate for an in-use add-on designed to account for unforeseen issues with technology or manufacturing to extend for a number of model years consistent with the expected useful of a locomotive (7-8 years). In this way, manufacturers can benefit from learning through a longer period of in-use data gathering and can be assured that the locomotives they design and produce will always be in compliance with EPA regulations. We have therefore provided a new interim regulatory option in §1033.150 (described in section IV of the preamble) that sets a longer period for the in-use add-on for NOx while manufacturers continue to evaluate the durability of the emission controls. At the same time, we have eliminated a regulatory provision that would have allowed the Tier 4 NOx standard to be delayed until 2017. In our final rule, the Tier 4 NOx and PM standards begin concurrently in 2015. As described in the final RIA, we believe such an approach is more appropriate reflecting not only our need to set the most stringent emission standards feasible, but also the considerable synergies that exist between the NOx and PM emission control technologies.

The commenter describing the statement of MECA at our public hearing has misunderstood the statement of MECA and their intent. The MECA testimony clearly said that the Tier 4 standards could be achieved by 2015, without specifically describing when the first catalyst samples would be available for locomotive testing. On September 27, MECA sent a letter to the Agency clarifying that SCR catalyst manufacturers are already providing catalyst samples for evaluation by locomotive manufacturers today, and would begin to provide samples for full-size, zeolite-based SCR locomotive evaluations in 2010, with production-intent SCR catalyst samples for extended field trials on locomotives available in the 2012-2013 timeframe. MECA further reiterated its position that this would allow full implementation of the Tier 4 NOx standard in 2015. We also believe that catalytic PM and NOx controls in other sectors have now developed to the point where systems are being introduced that integrate both an oxidation function (for PM control) and SCR (for NOx control). Integration of the catalytic controls for PM and NOx has reduced or eliminated the advantage of a stepwise approach to the introduction of PM and NOx emission standards from a workload perspective. We believe that it is technologically feasible to introduce both the Tier 4 NOx and PM standards in 2015.

Catalyst suppliers system integrators will have full-size, prototype Tier 4 systems ready for testing by 2010 (see MECA letter in docket EPA-HQ-OAR-2003-0190-0730). This will leave sufficient lead-time for two years of initial prototype testing, two years of extended field trials on production-intent designs, and one year for production implementation in Tier 4 locomotives by January of 2015. Metal CDPF systems are in full series production for truck applications in Europe. Metal substrate designs with 250 cm diameters are entering production for large nonroad applications. Catalyst system integrators such as Tenneco and Clean Air Systems are also developing catalyst systems for large engine applications that are built from parallel substrates produced in standard high-unit-volume heavy-duty truck substrate sizes in an effort to reduce costs and use proven catalyst mounting systems. For all of the reasons summarized here and in the final RIA, we have concluded that it is appropriate for the Tier 4 locomotive NOx and PM standards to begin in 2015.

While our updated analysis now leads us to conclude that we should begin requiring compliance with both the Tier 4 NOx and PM standards in 2015, several commenters stated that we should implement Tier 4 locomotive standards in 2013, or even earlier. We continue to believe that locomotive manufacturers do not have the resources to complete all of the engineering work needed to bring Tier 4 locomotives to market in that time frame while simultaneously upgrading their Tier 0, 1, and 2 designs to meet the new standards. Moreover, as described in the RIA, we considered an alternative scenario in which we would have pulled the Tier 4 standards ahead to 2013, but eliminated the new Tier 2 and Tier 3 standards. We found that, even if it were feasible to do so, diverting resources from the Tier 2 and Tier 3 standards in order to pull the Tier 4 standards ahead to 2013 would actually increase overall emissions.

Finally, we disagree with SCAQMD’s assertion that there are no technical reasons why manufacturers cannot create Tier 4 locomotives earlier using multiple high-speed nonroad engines in line-haul applications. This ignores the fact that medium-speed engines have significant efficiency and durability advantages over high-speed engines, and these advantages are important for line-haul applications. Moreover, the redesign effort required to produce 4,000 hp line-haul locomotives using multiple high-speed engines could very well take more time than would be required to produce Tier 4 locomotives using medium-speed engines.

10.2.2 Additional Lead-Time Needed to Establish Locomotive Catalyst Deterioration

What Commenters Said:

GE commented that it believes that if greater than expected deterioration is seen, it will most likely be due to a fundamental shortcoming in the technology when exposed to the harsh railroad environment. The commenter stated that it believes three years of actual in-use operation may be sufficient to expose any expected problems; however, if the solution involves more than just minor design adjustments, the commenter stated that three years would not be enough time to find, validate, and apply solutions to new locomotives. GE further noted that if unexpected deterioration does occur and is only due to easily-corrected minor miscalculations, the solution would be implemented in the shorter time frame EPA has proposed. The commenter noted that if unexpected deterioration is due to a more fundamental technology shortcoming, the useful life approach or the ability to apply for additional time would provide the manufacturer a more realistic schedule in which to address it.

GE further commented that, with regard to the proposed in-use deterioration add-on being applied to the first 3 model years of the Tier 4 PM and NOx standards, it believes that EPA should include the proposed deterioration adjustments of 40 CFR 1033.150(f) for model years 2015-2017 but should extend the allowance for the full useful life of these locomotives to take into account the possibility that a major redesign is needed to resolve a problem. The commenter stated that, alternatively, EPA could allow a manufacturer to request and obtain approval to continue to apply these factors after the three-year period elapses, based on a demonstration that more time is needed to resolve the issue.

Letters:
General Electric Transportation (GE)OAR-2003-0190-0590.1

Our Response:

As we note in Chapter 4 of the RIA, it is reasonable to conclude that aftertreatment components will be durable in the locomotive environment for model years 2015 and later. The information EPA relies on shows that aftertreatment components expected to be used have proven durable in other applications and should also be durable in locomotive applications. While we agree in concept with GE's comment that NOx catalyst durability cannot be demonstrated with absolute certainty without testing a significant number of locomotives under in-use conditions, the Clean Air Act requires us to base our standards on technology that "will be available" rather than technology that is already proven to a certainty for all conceivable engines.

Nevertheless, we have determined that it would be appropriate to extend the period over which an in-use adjustment factor would apply for NOx emissions. Should durability problems occur, this extension will provide manufacturers with sufficient lead time to implement design changes needed to correct such problems. It is important to note, however, that adjustments allowed during the extended should be smaller than those proposed, because the possible environmental consequences of an extended in-use adjustment at the larger level are not justified. Under the final regulations, manufacturers will have the option of applying the larger proposed adjustments for three model years or the new smaller adjustments for the extended period.

We have not provided the same extended period for the PM in-use adjustment factors because the deterioration mechanisms and expected performance of the PM control technologies we project that manufacturers will use to comply with our Tier 4 standards are much better understood. See Chapter 4 of the RIA for a complete description of the deterioration mechanisms and in-use performance we project will be realized through the application of Tier 4 NOx and PM control technologies.

10.2.3 Stringency of Tier 3 and Tier 4 Locomotive Standards

What Commenters Said:

EMD commented that it believes that EPA should rethink basing the Tier 3 and Tier 4 switch standards on high-speed nonroad engine technology, because of the unproven nature of such technology in rail service and because of the loss of the benefits of medium-speed engines.

AAR commented that the railroads are concerned about the disparity between the Tier 4 NOx standard for locomotives and the Tier 4 NOx standard for marine engines. The commenter noted that, as EPA discusses in its RIA, a marine engine achieving a 1.3 g/bhp-hr NOx standard would only meet a 1.7 g/bhp-hr standard when tested to the locomotive duty cycle. The commenter noted that its understanding is that locomotive and marine engines of comparable horsepower are very similar and should have virtually identical emissions characteristics. The commenter noted that EPA dismisses the concern over a disparity in the standards applicable to locomotive and marine engines by making several observations, and stated that it does not believe that any of the observations hold up to scrutiny (marine engines are starting from a higher NOx regulatory limit, locomotives will benefit from stop/start, the main engines of a comparable size will be subject to Tier 4 NOx standards three years sooner). The commenter raised the concern that railroad operating environment provides greater engineering challenges than the marine environment as they have comparatively little space for aftertreatment, are subject to high temperatures in tunnels, and operate at high altitudes. The commenter stated that if there will be a difference between the emissions standards for comparable locomotive and marine engines, EPA should offer a better explanation.

AAR also noted that in the preamble EPA asked whether additional NOx reductions (beyond the proposed Tier 3 line-haul standards requiring a 50% reduction PM emissions reduction and maintaining the Tier 2 NOx level, effective 2012) would be feasible for Tier 3 locomotives. The commenter stated that additional reductions for Tier 3 NOx would not only have unacceptable consequences for the railroads and locomotive builders, they also would be contrary to the public interest and undermine EPA's objectives. The commenter further noted that, as stated in the preamble, additional NOx reductions could be obtained through retarded engine timing, but the price would be a significant fuel penalty, with an increase in both carbon and PM emissions. AAR also commented that add-on exhaust gas recirculation (EGR) would not be a good option, as it would entail a significant fuel penalty, increased carbon emissions, and would discourage railroads from buying newer, lower emitting locomotives and divert resources from developing Tier 4 locomotives. The commenter noted that railroads are not going to be interested in buying locomotives with short-term technology that would only be used for a few years; the commenter believes that equipping Tier 3 locomotives with a short-term technology would provide the railroads with an incentive to delay the acquisition of new locomotives. Further, the commenter stated, the railroads are capable of keeping existing units in service rather than replacing them with new technology through the remanufacturing process. AAR also commented that locomotive builders have finite resources to devote to a market where an average of 773 new locomotives are put into service each year—if they are forced to devote resources to a short-term technology such as EGR (which is similar in necessary development time to SCR systems), the development of the next stage in emissions technology, aftertreatment-equipped locomotives, would likely suffer. Lastly, AAR commented that it found EPA's statement in the preamble that "a Tier 3 NOx standard below 5 g/bhp-hr might be achievable with a limited impact if additional engineering resources were invested to optimize such a system for general line-haul application" to be puzzling.

Letters:
Association of American Railroads (AAR) OAR-2003-0190-0566.1
Electro-Motive Diesel, Inc. (EMD) OAR-2003-0190-0594.1

Our Response:

We disagree with EMD's comment that EPA should not base the Tier 3 and Tier 4 switch standards on high-speed nonroad engines. Since switch locomotives using high-speed engines are currently being produced in greater numbers than medium-speed switch locomotives, they are an appropriate basis. Moreover, we do not believe that these switch standards will necessarily result in the loss of medium speed engines from switch rail service. EMD recently introduced the low emission 710ECO series medium speed engines for switch service, which could serve as a developmental engine platform for Tier 3 and Tier 4 medium speed switch locomotive applications. In chapter 4 of the Final RIA, we describe the technologies that we expect to be used to meet Tier 3 and Tier 4 emissions with medium speed engines. A summary of the technologies we expect will be used for medium speed switch locomotives to meet the Tier 3 standards is included in table 4-1 of the RIA (and was also included in the Draft RIA, in table 4-1). We believe that the SCR and CDPF technologies described for Tier 4 medium duty engines can be applied to locomotive switch applications, that these engines will be available in the marketplace, and that we should not allow increased emissions standards for a particular engine type.

In response to AAR's comments regarding the relative parity of the locomotive and marine Tier 4 NOx standards, we are finalizing the most stringent NOx emission standards that we believe feasible for both locomotive and marine diesel applications giving full consideration to the numerous differences between these applications. For example, many Category 2 marine engines certified to the Tier 2 marine standards differ from locomotive engines and include significantly higher power rating and per-cylinder displacements. As described in Chapter 4 of the Final RIA, large-bore medium speed Category 2 marine engines will need a higher NOx conversion efficiency when applying SCR to their Tier 2 engine designs than will be the case for locomotive applications. Regarding the differences in peak exhaust temperatures encountered between locomotive and marine applications, the peak temperatures encountered at altitude for the most extreme operation by heavy-haul trains in unventilated tunnels are still well below the temperatures at which significant thermal degradation occurs when using base-metal zeolite urea SCR NOx emissions controls. Please refer to our response to comments in section 10.2.5 of this document for further discussion of the impact of high altitude tunnel operation on SCR durability. Regarding the space available for the emissions control systems, please refer to the detailed discussion of packaging feasibility in section 4.3.3.

As explained in Section III of the preamble, we agree with AAR's evaluation regarding a number of the issues related to setting a more stringent Tier 3 NOx standard. Hence, we are finalizing a Tier 3 program that does not reduce the NOx emission standard below the level set in our Tier 2 program.

10.2.4 Technology Transfer to Locomotive from Other Sectors

What Commenters Said:

MECA noted that DPFs are commercially available today, in many retrofitted heavy-duty vehicles and new light-duty vehicles worldwide. The commenter further noted that new highway vehicles will be equipped with DPFs to meet the 2007 highway diesel requirements and the light-duty Tier 2 requirements. MECA commented that DPFs have been successfully installed and used on thousands of nonroad applications such as: mining, construction, and materials handling equipment, where vehicle integration has been challenging. The commenter also noted that 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. The commenter stated that they have provided in excess of an 85 percent reduction in PM emissions, and some systems have been operating effectively for over 650,000 kilometers. Further, a limited number of these active DPF systems have also been safely equipped on marine vessels in Europe to control PM. MECA also offered examples of demonstration projects in the U.S. evaluating DPF feasibility for locomotive and marine engines: a U.S. Navy work boat/barge retrofitted with an active DPF system, active DPF systems (similar to those equipped on European locomotives) have been retrofit on two 1500 hp switcher locomotives operating in rail yards in southern California, and DPFs will be demonstrated on two commuter rail locomotives operating between Oakland and Sacramento.

MECA commented that, recently, metal substrate filter designs have been developed and introduced for PM control of diesel engines. The commenter noted that 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. The commenter also noted that these metal substrate filter designs have been verified by the California Air Resources Board as a Level 2 retrofit device ($\geq$50% PM reduction) on a range of highway diesel engines, used by an engine manufacturer 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. Lastly, the commenter noted that their more open designs allow them to operate over very long timeframes without the need for cleaning the substrate of trapped lubricant oil ash.

MECA commented that diesel oxidation catalysts (DOCs) are a well-proven technology for oxidizing gaseous pollutants and toxic hydrocarbon (HC) species present in diesel engine exhaust, and are effective at reducing diesel PM emissions through the catalytic oxidation of soluble hydrocarbon species adsorbed on soot particles formed during combustion. The commenter noted that DOCs can also oxidize nitric oxide (NO) present in the engine exhaust to nitrogen dioxide (NO_2), which can be used to oxidize soot captured on a DPF at relatively low exhaust temperatures (“passive filter regeneration”) or to improve the low temperature performance of SCR catalysts by providing a more kinetically variable mixture of NO and NO_2 to the SCR catalyst. The commenter suggested that both the oxidation of soluble PM species and NO oxidation pathways could be useful in meeting the proposed Tier 4 locomotive and marine diesel standards. MECA noted that over two million oxidation catalysts have been installed on new heavy-duty highway trucks since 1994, and many new 2007-compliant heavy-duty trucks on the market 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. Additionally, oxidation catalysts have been used on millions of diesel passenger cars in Europe since the early 1990s, and they have been installed on over 250,000 off-road vehicles around the world for over 30 years.

MECA commented that SCR technology is a proven NOx control strategy that has been used to control NOx emissions from stationary sources for over 20 years. The commenter noted that more recently, SCR has been applied to mobile sources including trucks, nonroad equipment, and marine vessels; applying SCR to diesel-powered engines provides simultaneous reductions of NOx, PM, and HC emissions. The commenter noted that open loop SCR systems can reduce NOx emissions from 75 to 90 percent, and closed loop systems on stationary engines have achieved NOx reductions of greater than 95 percent. Modern SCR system designs have been detailed for mobile source applications that 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. The commenter noted that heavy-duty engine manufacturers worldwide are currently offering urea-SCR systems in highway truck applications, combined DPF+SCR system designs are being considered to meet the 2010 heavy-duty highway standards, and DOC+SCR systems are also being used commercially in Japan in new diesel trucks. The commenter also noted that several technology providers are developing and demonstrating retrofit SCR systems for both highway trucks and off-road equipment.

MECA commented that it recognizes that the proposed Tier 4 locomotive and marine diesel engine standards present engineering challenges, but it believes those challenges can and will be met. The commenter stated that it believes that the key will be to employ the systems approach identified in the NPRM consisting of the further evolution of locomotive and marine diesel engine designs, the use of advanced emission control technology, such as diesel particulate filters and SCR catalyst systems, the use of ULSD, and the use of low ash and sulfur-containing lubricants. The commenter noted that it has reviewed EPA’s Tier 4 technical feasibility discussion and agrees with EPA’s technical assessments. MECA further commented that it and its member companies firmly believe that high efficiency and durable diesel particulate filter and SCR catalysts meeting the EPA technical assumptions for the proposed Tier 4 standards on locomotive and marine diesel engines will be available in the 2015 timeframe. The commenter also stated that it believes that both Tier 4 locomotive and marine diesel SCR applications will benefit from continued development efforts on SCR systems that will be driven by much higher volume applications on light-duty vehicles, heavy-duty vehicles, and off-road diesel-powered equipment.

GE commented that with the Tier 4 NOx standard, the solutions are being developed by the manufacturers of aftertreatment devices who have little experience with the parameters of the locomotive operating environment. The commenter noted that locomotive manufacturers will be unable to ship locomotives if the standards are not achieved or if the aftertreatment systems are made available by the suppliers but the catalyst fails. The commenter stated that because of this, the locomotive manufacturers bear potential penalties under the proposal for failing to achieve the standard and the railroads that bear the severe economic disruption associated with locomotives that are unable to operate due to nonconformities with emissions standards. GE stated that it believes this adversely impacts the fair market dynamics of the railroad industry. The commenter further stated that it believes that the deterioration studies for the zeolite catalysts show that a beginning of useful life emissions level of 0.8 g/bhp-hr will degrade to 1.9 g/bhp-hr by the end of the locomotive’s useful life. The commenter stated that, for this reason, if EPA proceeds with a Tier 4 standard that requires aftertreatment, it is incumbent on EPA to ensure that the suppliers of the control systems will have controls available for testing and that the catalyst has been shown to maintain its effectiveness. GE commented that it believes that a regulatory review of catalyst deterioration in 2010 is both appropriate and necessary to ensure that the Tier 4 NOx standard is achievable, regardless of whether EPA sets the standard at 1.9 or 1.3 g/bhp-hr.

Letters:
General Electric Transportation (GE)OAR-2003-0190-0590.1
Manufacturers of Emission Controls Association (MECA) OAR-2003-0190-572.1

Our Response:

MECA's statements are consistent with our observations and are similar to what EPA has stated within the RIA. MECA's comments regarding performance and durability of DPF, SCR, and DOC systems and successful demonstration in marine vessels are also consistent with recent EPA laboratory test results (see docket EPA-HQ-OAR-2003-0190).

As described in our response to 10.2.1, we take seriously the locomotive manufacturers concerns about the unique parameters that locomotive engines operate under (most importantly tunnel operation), and we worked with the industry including the commenters here to evaluate tunnel operating conditions as summarized in the RIA. We believe that the challenges facing application of these technologies to locomotives such as packaging constraints, the exhaust chemistry encountered, the temperatures encountered, shock, vibration and ambient conditions are not fundamentally unique to the locomotive sector and successful design approaches have been developed and implemented to address each of these issues in other diesel engine applications as shown by our testing at the National Vehicle and Fuel Emission Laboratory. We believe that the 1.3 g/bhp-hr standard adequately takes into account SCR catalyst degradation over the useful life of a locomotive, particularly when considering that thermal degradation is the primary means of catalyst deactivation and that the worst case exhaust temperatures encountered during locomotive operation are notably less severe than those encountered with heavy-duty highway truck applications as described in our test report on locomotive tunnel operation and our RIA.

10.2.5 Long-Term Durability of Locomotive Aftertreatment Technologies

What Commenters Said:

GE commented that it appears that EPA is relying in part on assurances from MECA's claims that the catalysts represent no difficulty in terms of deterioration. The commenter noted that MECA has cited [to GE] stationary applications as support for the concept that units can operate with zeolite for long periods at high temperatures, suggesting that the same should be true for locomotives. The commenter stated that they believe this statement is not correct for the following reasons: most stationary turbines result in exhaust temperatures in the range of 450 °C with little variation, while locomotives have operations that can reach 700 °C for significant periods of time; stationary systems have ample space available for aftertreatment systems (thus assuring appropriate mixing of ammonia with the exhaust prior to the SCR system), catalyst change-out rarely occurs because standard operating practice is typically to add new catalyst bricks to the existing system; catalysts systems used in stationary applications do not experience the frequent, severe mechanical shock loads or exposure to the elements that are present in locomotive operation; and reducing a low NOx stream with a urea-based SCR requires lower concentrations of urea (and thus lower ammonia concentrations due to slip).

GE also commented that there are a number of data sources clearly showing that catalyst degradation is governed by accumulated exposure to high temperature over time. The commenter raised that concern of the length of exposure to high temperatures for the DOC and the SCR zeolite catalyst in the locomotive environment. The commenter noted that, at 72 FR 15981, EPA stated that the Agency's review of long term catalyst durability leads to the conclusion that durable catalysts already exist and have been applied to urea SCR NOx emissions control systems that are similar to those EPA expects to be implemented in the locomotive and marine environment. The commenter stated that while EPA has reviewed the data available prior to proposal for the truck industry, EPA did not take into account that the catalyst system used in the truck industry cannot be used successfully in locomotives due to the longer periods over which the catalyst will be exposed to high operating temperatures in locomotives. The commenter stated that these high temperatures increase the potential for thermal degradation of the zeolite catalyst from the locomotive exhaust to a degree that is substantially higher for locomotives than for trucks.

NJDEP responded to the request for comment on the comparative and unique engine scenario NOx control information when the engine is equipped with either zeolite or vanadium SCR and operating on the marine and locomotive duty cycle. The commenter stated that locomotive and marine engine applications are not uniquely different from highway and nonroad applications. The commenter noted that many vanadia-based SCR units have been applied successfully to both locomotives and marine engines and have performed for many operating hours with excellent performance. The commenter further noted that zeolite-based SCR is being studied for these applications. The NJDEP commented that with the combination of Best Available Technology (BAT) DPF + SCR, both types of SCR are protected from known catalyst poisons by the BAT DPF that removes 99+% of solid metal ash poisons and surface glaze compounds thus protecting the SCR unit from progressive performance decline. Thus, the commenter stated, the high level of SCR NOx performance is expected to be maintained.

NJDEP also responded in reference to request for comment on whether 45% DOC efficiency is required by certain types of SCR systems to maintain greater than 94% zeolite SCR efficiency to meet the Tier 4 1.3 g-bhp-hr NOx standard under the temperature range of the line-haul duty cycle. The commenter responded that the engine baseline NOx level (which would require 94% NOx reduction to reach 1.3 g/bhp-hr NOx) is 22 g/bhp-hr, the remanufactured engine Tier 0 and Tier 1 NOx standard is 7.4, and Tier 2 is 5.5 g/bhp-hr. The commenter also noted that the new Tier 3 emission standard is 5.0 g/bhp-hr NOx. NJDEP further commented that a 94% SCR NOx efficiency applied to 5.0 g/bhp-hr engine out baseline would achieve 0.3 g/bhp-hr NOx tailpipe emissions, and thus the 94% conversion rate mentioned in the NPRM's question 3 will not be needed. The commenter stated however, that it believes that 94% NOx is remarkably achievable with SCR NOx technology and it can be employed in the "systems approach" to bring improvements to diesel engine specific fuel consumption as noted in the detailed comments and elsewhere. The commenter further stated that it believes that more than 45% DOC oxidation of NO to NO_2 is achievable with a platinum DOC from below 200 °C to around 400 °C depending on space velocity and catalyst formulation. NJDEP also noted that BAT DPF technology, if used for locomotives, will certainly meet the 0.01g/bhp-hr PM standard (the current HD 2007 standard) and remove all insoluble solid lung alveoli nanoparticles that are regarded by health authorities as the size specific fraction of most concern.

Regarding soot exposure, NJDEP noted that engine-out soot will be cleansed with a BAT DPF system and therefore soot will not affect SCR catalysts. The commenter stated that it is noted that so-called partial filters would not prevent SCR soot and metal-ash exposure. The commenter recommended that only verified best available filter technology be permitted. The commenter suggested that there is also a need for a thorough SCR NOx verification procedure (already started in Europe with an open invitation to EPA to join). Lastly, the commenter stated that SCR NOx catalyst high temperature hydrothermal exposure limits have improved and low and high temperature SCR NOx selectivity is also improving due to manufacturer development work.

Letters:

General Electric Transportation (GE)	OAR-2003-0190-0590.1
New Jersey Department of Environmental Protection (NJDEP)	OAR-2003-0190-0562.2

Our Response:

With regard to the GE's concern about catalyst deterioration due to accumulated time at high temperatures, and the potential for 700 °C locomotive exhaust temperatures, EPA worked with the locomotive manufacturers and the railroads to determine maximum post-turbine exhaust temperatures under worst case operational conditions. We worked jointly with GE, EMD, Union Pacific Railroad, BNSF Railway, and Southwest Research Institute to conduct high-altitude testing of two Tier 2 locomotives operating in the rearmost positions within a multiple locomotive consist pulling a heavy freight train through multiple unventilated tunnels in the Donner Pass region of California and Nevada in August, 2007. Exhaust temperatures, other engine data, locomotive data and ambient conditions were monitored over the same route used by GE during its development of the GEVO locomotive. Maximum post turbine exhaust temperatures were encountered during operation in a long unventilated tunnel where ambient air temperatures exceeded 100 °C (212 °F) due to the exhaust flow and heat rejection from the locomotives into the tunnel. Under these extreme conditions, the Tier 2 GE locomotive reached a maximum post-turbine exhaust temperature of 560 °C. During analysis of the engine and locomotive data during the tests, it became clear that this represented a maximum achievable exhaust temperature, and that the maximum temperature was self-limited by measures taken by the electronic engine management to prevent engine damage that could result from exceeding oil temperature limits, coolant temperature limits and the temperature limits of engine components. The results have been shared with GE, EMD, and AAR, and a detailed report of this testing is included in docket EPA-HQ-OAR-2003-0190.

We relied on data generated during the development of base-metal zeolite systems for on-highway diesel and other applications in our analysis. The MECA citation of stationary gas turbine applications (see section 10.2.4, above) is relevant, although GE's characterization of the operating conditions is not accurate for gamma-exchanged iron zeolite (Fe-zeolite) SCR gas-turbine applications. Typical gas-turbine applications using exhaust heat recovery operate with exhaust temperatures at or below 450 °C, as stated in the comments, and thus have been able to use vanadium-based SCR systems for NOx control. Extruded vanadium catalysts and coated vanadium-tungsten-titanium mixed oxide (VWT) catalysts have maximum operating temperatures of 540 °C and 600 °C, respectively. Above those temperatures, vanadium-based catalysts suffer irreversible thermal degradation. The maximum operating temperatures for vanadium-based SCR catalysts prevented their application to gas-turbine engines operated without exhaust heat recovery, which have sustained operation with exhaust temperatures of 550 to 650 °C. Fe-zeolite SCR was originally developed for precisely this special case of controlling NOx emissions from gas-turbines operated without exhaust heat recovery and this is the gas turbine application referred to by MECA. The use of Fe-zeolite SCR for these applications allowed operation at the much higher exhaust temperatures of gas turbines operated without exhaust heat recovery and also improved NOx conversion efficiency above 450 °C. Similarly high exhaust temperatures are encountered in heavy-duty diesel applications during forced regeneration of PM traps, thus for U.S. 2010 truck applications that combine forced PM regeneration with SCR, the primary control technology for NOx has been Fe-zeolite SCR rather than vanadium-based SCR. The Fe-zeolite SCR systems developed for U.S. highway truck applications have improved NOx reduction efficiency and thermal durability relative to systems previously developed for stationary gas turbine applications. Other base-metal zeolite catalyst formulations such as Cu-zeolite SCR have similar thermal durability to Fe-zeolite SCR and improved low temperature NOx reduction efficiency. Vanadium-based SCR systems are in production for truck applications in Europe, but these systems are not subjected to the higher temperatures of forced PM regeneration since the PM standards currently in place in Europe are not sufficiently stringent to require the use of PM traps. We understand that the thermal degradation of catalysts is a function of time, temperature and exhaust chemistry. The MECA gas turbine example represents conditions of sustained operation at higher temperatures than would be encountered in locomotive operation without causing severe damage to the locomotive engine. Durability data generated during development of high-temperature capable base-metal zeolite SCR systems for U.S. and European trucks is also consistent with MECA's example.[2]

GE also cited the frequent and severe mechanical shock present in locomotives as a durability concern. The shock requirements cited for locomotive applications, while greater than those for stationary applications, are similar to, or less than, the levels encountered in nonroad applications and on-highway applications that will be using similar SCR control technology (as described in Chapter 4 of the RIA and in section 10.4.8 below). In Chapter 4 of the RIA, we also

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[2] Smedler, G. "NOx Emission Control Options", SAE Heavy Duty Diesel Emissions Symposium, Gothenburg, Sweden, September 10-12, 2007.

describe how ammonia slip can remain low at high NOx reduction efficiency even with relatively high NOx feedgas rates through the use of static mixers, closed-loop urea dosing, and the use of a highly selective ammonia slip catalyst. Data published by Englehard (a catalyst manufacturer) and DAF (a European truck manufacturer) at the Society of Automotive Engineers (SAE) 2006 World Congress showed emissions results obtained using an ammonia slip catalyst configured into a hydrothermally aged SCR catalyst system operated at high space velocities. The data showed that greater than 90% NOx removal could be achieved with less than 25 ppm of ammonia slip even at excessive dosing rates of greater than 1.3:1 and with NOx feedgas concentrations higher than those of Tier 2 locomotives. More moderate dosing rates near 1:1 resulted in peak ammonia slip of 6 ppm or less.[3] Recent engine tests conducted by EPA also showed similar results of very low ammonia slip and high conversion at high engine-out NOx concentrations comparable to those of a Tier 2 GE locomotive (see docket EPA-HQ-OAR-2003-0190).

MECA, which represents a number of catalyst companies with extensive experience applying catalysts to a wide range of applications, states within their comments that they do not see circumstances unique to locomotive operation with respect to exhaust chemistry, temperature, vibration, shock or ambient conditions that have not already been encountered for application of similar PM and NOx controls to other diesel engine applications such as heavy-duty on-highway or nonroad diesels. MECA's assessment is consistent with our assessment of application of catalyst technology to locomotives, which is described in detail in Chapter 4 of the Regulatory Impact Analysis. Considering that fundamental catalyst research for NOx and PM control will not be necessary, the availability of hardware for testing is available in a timeframe that is consistent with a locomotive manufacturer's timeframe for hardware development. The timeframe needed for the introduction of engine and control system hardware to meet new emission standards was summarized by a locomotive builder in a presentation delivered at a symposium on locomotive emissions control hosted by the California Air Resources Board in Sacramento California on June 6, 2007. That presentation suggests that if catalyst samples can be provided for testing by 2010, the introduction of fully compliant locomotives can begin in 2015.

Hence, while we do reflect that in certain aspects of design and operation locomotive engines differ from their on-highway and nonroad counterparts, with regard to the specific instances that we have considered for technology transfer, we can conclude that, from the experience gained from on-highway and nonroad emission control development, technology transfer can occur.

10.2.6 Tunnel Operation

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[3] Hünnekes, E.V., van der Heijden, P.V.A.M., Patchett, J.A. "Ammonia Oxidation Catalysts for Mobile SCR Systems.

What Commenters Said:

AAR commented that locomotive engines present unique issues insofar as catalysts are concerned. Locomotives operate in tunnels in trains which have locomotives trailing other locomotives; the temperatures in the tunnels due to the exhaust from multiple locomotives are much higher than the temperatures catalysts will be exposed to when installed on other mobile source engines. Another important operating factor is vibration, exacerbated by the location of aftertreatment devices above the engine. Whether catalysts can maintain their efficiency at such high temperatures and extended periods of significant vibration is at best unknown.

EMD noted that EPA, in cooperation with Union Pacific, planned to conduct tunnel tests of EMD and GE locomotives for the purpose of understanding potential thermal aging deterioration of aftertreatment systems. The commenter noted that in measuring the temperatures around the test locomotives in tunnels, and the temperatures in the exhaust system, EPA should be cognizant of the challenges to exhaust aftertreatment systems posed by other factors of tunnel operation. The commenter provided the example that one of its rail customers operates locomotives in severe conditions that result in soot emissions that cause severely shortened maintenance intervals for locomotive air filters. The commenter noted that while a particulate filter will mitigate the soot emissions from individual locomotives, there are impacts on the aftertreatment system operation, including: 1) an oxidation catalyst - partial-flow particulate filter combination, as suggested by EPA, may not be appropriate here as particulate emissions in tunnels are likely to consist of a much higher fraction of soot than has been measured in open-air testing (if a partial-flow filter passes a significant fraction of the soot, fouling of the downstream selective catalytic reduction unit can be expected); 2) if a wall-flow filter is used for locomotives subject to tunnel operation (which, since locomotives are freely interchanged among railroads, can be any locomotive) its regeneration intervals will be severely shortened, with consequent increases in fuel consumption and potential operational impacts; lastly, 3) a wall-flow filter could be subject to uncontrolled passive regeneration when the locomotive leaves the tunnel and ingests fresh air (since the unit will be operating at full load), and the system may not survive such an occurrence. The commenter suggested that EPA make sure that its test is representative of the most severe tunnel operation, and carefully observe the effect of the tunnel on locomotive operation and emissions.

Letters:

Association of American Railroads (AAR)	OAR-2003-0190-0566.1
Electro-Motive Diesel, Inc. (EMD)	OAR-2003-0190-0594.1

Our Response:

EPA has worked with EMD and a number of other rail industry partners to measure operating conditions “representative of the most severe tunnel operation.” In that testing, we observed significant engine de-rate occurring during operation within unventilated tunnels to prevent engine overheating. While the commenter is certainly correct that operation in unventilated tunnels does represent operation under oxygen depleted conditions, the higher equivalence ratio that would be attained if full-load were maintained through the tunnel is never realized because of engine de-rate due to the inability to effectively reject heat from the engine and locomotive under such high ambient temperature conditions. Also, the duration of operation in unventilated tunnels is relatively short from the perspective of DPF loading, particularly considering the relatively large DPF volume that will be required due to lower acceptable backpressure limits of locomotive engines in general and EMD 2-stroke engines in particular. Soot loading and passive regeneration within DPFs used for current heavy-duty truck applications is carefully monitored by calculating soot loading based on operational history, calculated or measured engine equivalence ratio, calculation of NO_2 available for passive regeneration or measurement of upstream NOx using zirconia sensors, and by monitoring inlet temperature and modeling catalyst temperatures. We expect a similar developmental effort and analogous controls will be applied to DPF systems used with locomotives.

With respect to items 2 and 3, the commenter did not provide an estimate of the increase of soot loading from tunnel operation, which would be necessary to evaluate whether or not wall-flow trap soot capacity would be exceeded for a given DPF size during the approximately fifteen minutes or less of sustained operation within an unventilated tunnel. Whether or not increased active regeneration would be needed or whether or not uncontrolled regeneration would occur would largely be a function of how much passive regeneration has occurred during locomotive operation and how much soot loading occurred within the trap irrespective of tunnel operation. Considering that current Tier 2 locomotives have approximately five to ten times the NOx to PM ratio of current on-highway trucks and considering that the temperature necessary for passive regeneration via NO_2 is available for most of the loaded locomotive throttle-notches, and also considering that engine-out PM emissions will be reduced further with the introduction of the Tier 3 PM standards (thus further improving the NOx to PM ratio for passive PM regeneration) we expect that there will be sufficient passive PM regeneration to prevent either uncontrolled PM regeneration or increased need for active PM regeneration under these scenarios. When taking into consideration the opportunities for passive PM regeneration within locomotive applications, it seems unlikely that the safe PM capacity of such a large PM trap system would be exceeded with the result being uncontrolled regeneration, particularly with such short durations of operation within unventilated tunnels.

10.2.7 Expected Performance of Locomotive Aftertreatment Technologies

What Commenters Said:

EMA commented on EPA's statement that the introduction of "CDPF systems utilizing metal substrates are a further development that trades off a degree of elemental carbon soot control for reduced backpressure, improvements in the ability of the trap to clear oil ash, greater design freedom regarding filter size/shape, and greater robustness" (72 FR 15980). EPA goes on to state that metal-CDPFs "were initially introduced ... to achieve approximately 60% control of PM emissions [and that] recent data from further development of these systems for Euro-4 truck applications has shown that metal-CDPF trapping efficiency for elemental carbon PM can exceed 70% for engines with inherently low elemental carbon emissions." EMA agrees that metal-CDPFs may have some potential to address several of the major questions concerning particulate exhaust filters. However, the basic limitation of particulate reduction efficiency must be recognized. Consequently, efficiencies above 60% should not be assumed for metal-CDPFs.

EMA also commented on EPA's claim that data from locomotive testing confirms a relatively low elemental carbon fraction and a relatively high organic fraction for PM emissions from medium-speed Tier 2 locomotive engines. EPA then states that a system with an oxidation catalyst and a metal CDPF would reduce overall PM emissions from a locomotive or marine diesel by upwards of 90%. While this may be true under some operating conditions on some engines, this does not account for the fact that the cycle emissions will be much less since the test cycles include operating points which will have less efficiency. This is especially true of the locomotive cycles, which include operation at idle for 59.8% of the time for switchers, and 38% of the time for line-haul locomotives. The exhaust temperature is less than 260°C at idle and at throttle notches below 3 for medium-speed locomotives. Also, the efficiency of a metal-CDPF cannot be extrapolated to smaller high-speed engines (or to purpose-built large marine engines). Consequently, using the high end of aftertreatment efficiency estimates as the generally achievable efficiency will lead to potentially infeasible standards. Stated differently, the basic limitations relating to the particulate removal efficiency of the metal-CDPF cannot be assumed away.

In its comments, MECA provided responses to the NPRM's request for detailed technical comments on the proposed Tier 4 standards and the use of catalyst-based controls to achieve the proposed emission levels, specifically on zeolite SCR performance/durability. The commenter stated that the available database of information on zeolite-based SCR catalysts shows that they are capable of maintaining high NOx conversion efficiencies at space velocities in the range of 40,000/hr at extended operations in 600 °C exhaust temperatures. The commenter also noted that some recent references supporting this statement were included in the Draft RIA.

MECA commented that 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. The commenter also noted that the new "clean diesel" world of technologies also includes other options for catalyst-based controls for NOx, such as NOx adsorber catalysts (which are in commercial production on a number of light-duty and medium-duty diesel vehicles offered by various manufacturers). The commenter provided many examples of various technologies, demonstration projects, and technical papers in its comments.

MECA also commented that it agrees with EPA's technical discussion concerning the technical feasibility of designing SCR systems with low ammonia slip characteristics. The commenter stated that low ammonia slip SCR systems (e.g., 20 ppm or less ammonia peak concentrations in the exhaust exiting the SCR catalyst) have been and can be designed for locomotive or marine diesel applications. The commenter stated that achieving low ammonia slip includes proper sizing of the SCR catalyst and the design and control of the urea dosing system. MECA cited work being completed as part of the large U.S. Department of Energy Advanced Petroleum-Based Fuels-Diesel Emission Control Program, which includes evaluations of two different DPF+SCR systems on a modified heavy-duty highway engine. The commenter noted that in these systems, with only open loop control of the urea-dosing systems and the use of ammonia slip catalyst at the exit of the SCR catalysts, average ammonia levels measured in the exhaust during transient and steady-state testing were 6 ppm or less after engine aging these systems for 6000 hours.[4] The commenter stated that in the case of performance measured over the Federal heavy-duty transient test cycle, both of these aged systems showed ammonia slip levels of less than 1 ppm on average across the transient test cycle.

MECA further commented that, as cited by EPA in the Draft RIA, closed-loop control of SCR systems is now being developed for U.S. light-duty and heavy-duty diesel vehicles and will be introduced into the market between 2008 and 2010. The commenter noted that these closed-loop control systems will operate under conditions that maximize NOx conversion efficiencies while minimizing ammonia slip. Additionally, the commenter noted that catalyst manufacturers have available and continue to develop ammonia slip catalysts that can be placed after the SCR catalyst to selectively convert ammonia to nitrogen. (The commenter noted various SAE papers in its comments regarding ammonia slip catalysts.)

Finally, MECA commented that DOCs are a well proven, durable catalyst-based technology that have accumulated millions of miles of service on light-duty and heavy-duty vehicles. The commenter stated that, in particular, the ability for DOCs to oxidize NO to NO_2 is a critical pathway to the soot regeneration characteristics of catalyst-based DPFs that rely on the passive regeneration of soot. In some designs, these catalyst-based DPFs include a DOC upstream of either an uncatalyzed or catalyzed wall-flow ceramic filter. The commenter noted that literature on this issue includes numerous references to the use of retrofit catalyzed filters that feature a DOC+DPF configuration where the DOC is used to oxidize NO to NO_2 to facilitate soot regeneration at relatively low exhaust gas temperatures in the range of 200 to 350 °C. MECA also noted that in some cases, these DOC+DPF retrofit passive filters have been in service for many years and hundreds of thousand of miles of operation. (The commenter lastly noted that SAE papers number 2000-01-0480 and 2004-01-0079 are two references that provide evidence that passive soot regeneration facilitated by NO oxidation over a DOC is maintained after many thousands of hours of operation.)

GE commented that with regard to EPA's statement that "emissions of a new engine - and the emissions throughout much of the engine's life - will be closer to 0.8 g/bhp-hr" (Draft RIA, p. 4-30), it agrees that with significant engineering development it will likely be able to achieve a 0.8 g/bhp-hr level in an "as new" configuration in the locomotive environment using the appropriate catalyst. The commenter stated that its point of departure with EPA's view is the

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[4] "Demonstration of Potential for Selective Catalytic Reduction and Diesel Particulate Filters," presented by Magdi Khair, 11th DEER Conference, August 2005, online at: http://www1.eere.energy.gov/vehiclesandfuels/pdfs/deer_2005/session5/2005_deer_mcgill.pdf. This document is available in Docket EPA-HQ-OAR-2003-0190.

statement that the engine will be able to maintain that performance throughout its useful life. The commenter stated that it believes that, due to degradation of the catalyst (which has not been adequately accounted for in the proposed rule and which recent studies support), the proposed 1.3 g/bhp-hr level at end of useful life is not achievable.

GE also commented (in Appendix A of its comments) that it is concerned with the long-term achievability of the Tier 4 NOx standard using an SCR system, specifically due to catalyst deterioration. The commenter stated that it agrees with EPA on most aspects of the achievability of the emissions standards in the proposed rule. The commenter stated, however, that it continues to have concerns with the aspect of catalyst durability, specifically related to the ability of the catalyst to achieve 1.3 g/bhp-hr throughout the locomotive's useful life. GE commented that the NPRM was largely based on data that was developed and published generally in the 2005-2006 timeframe, with systems applicable to truck operations using a catalyst that will not perform adequately to achieve the proposed locomotive standards over the useful life. The commenter stated that numerous studies have since been published that further support its concern that the catalyst will deteriorate beyond the 10% rate EPA cited in the NPRM and beyond a rate that allows for compliance with the 1.3 g/bhp-hr limit throughout the locomotive's useful life.

GE also commented that the performance of a typical urea-zeolite catalyst is a function of temperature and is generally ineffective with exhaust gas temperatures below 200 °C but very effective for exhaust gas temperatures above 300 °C. The commenter noted that, given the range of engine operating conditions included in the locomotive test cycle and subsequent range of exhaust gas temperatures, the conversion efficiency of the SCR must be high enough under the conditions for which it is effective to compensate for the conditions where it is ineffective. For the high temperature (above 300 °C) operation, a conversion efficiency of ~84% is necessary to achieve an effective composite duty cycle NOx reduction of 76%. This is the effective duty cycle reduction required to lower engine out NOx from a Tier 2 level of 5.5 g/bhp-hr to the proposed Tier 4 level of 1.3 g/bhp-hr [(5.5-1.3)/5.5 = 0.76]. The need for these conversion levels is illustrated in a table (see OAR-2003-0190-0590.1, p.A-5 for table), for simplicity, the eleven power settings of a locomotive have been collected into three groups of exhaust gas temperature (less than 200 °C, between 200 °C and 300 °C, greater than 300 °C) (assuming normal ambient temperature and pressure conditions). The low temperature exhaust gas (<200 °C) group consists of the four locomotive operating conditions of idle, low idle, dynamic breaking and notch 1. The exhaust gas temperature of Notch 2 is between 200 °C and 300 °C. All of the power settings from notch 3 through notch 8 produce exhaust gas temperatures above 300 °C. As shown in the table, for an engine-out line-haul locomotive duty cycle NOx level of 5.5 g/bhp-hr, the SCR NOx conversion for high temperature operation must be at least 84% to stay under a 1.3 g/bhp-hr level.

EMD commented that, as noted by EPA in the June 25, 2007 industry meeting, aftertreatment applications to turbine engines are difficult because such engines will tolerate only minimal backpressure. The commenter noted that a turbocharged two-stroke cycle diesel engine is similar to a turbine engine, and can be thought of as a turbine engine with a reciprocating combustor. The commenter thus stated that application of aftertreatment devices to two-stroke engines poses many of the same problems seen with application of such devices to turbine engines. The commenter stated that the reason for the difficulties likely to be encountered with aftertreated two-strokes is that there is no pumping done in the cylinders (all of the pumping is carried out by the scavenging blower, in modern engines an exhaust-driven centrifugal compressor which pumps air through a constant orifice in the engine, set by the port sizes and the fact that approximately one-quarter of the cylinders are undergoing the scavenging process at one time). Consequently, the commenter stated, anything that has significant effect on the performance of the turbocharger compressor or its driving exhaust turbine will affect engine performance to a similar degree.

EMD also commented that the problems likely to be encountered from backpressure variation as devices increase soot and ash loading and then are cleaned or regenerated. The commenter stated that such variability increases by an order of magnitude the problems faced by the engine and aftertreatment system designers. The commenter noted that in designing an engine and turbocharger system for variable backpressure, (aside from the loss of performance and fuel consumption from increased backpressure) careful design must be exercised to avoid driving the turbocharger compressor into surge, in which it cannot support the pressure ratio across it and flow through the compressor reverses. EMD further noted that surge can be destructive to both the turbocharger and the engine air filters, located immediately upstream of the compressor. The commenter stated that ways of controlling the backpressure and its variation are likely to include the following:

- Increase of the size of aftertreatment devices—a larger device will provide lower backpressure for the same flow. (The commenter believes that this consideration casts further doubt on the size estimates provided by EPA.)
- Reduction of maintenance intervals for devices—if backpressure increases beyond the ability of regeneration to remedy due to progressive fouling of aftertreatment devices, one possible measure is to require more frequent cleaning or replacement of elements. (The commenter stated that it believes that this is why EPA should not set maintenance intervals for unproven devices, as EPA may inadvertently constrain the process in such a way that no solution is possible.)
- Reduction of the effectiveness of the aftertreatment devices—through increase in cell size, reduction of numbers of cells per square inch, etc.; which would throw more of the burden of emissions reduction back on the engine, increasing engine cost and, likely, fuel consumption.

With regard to temperature concerns, the NJDEP (0562.2) commented that SCR NOx catalyst high temperature hydrothermal exposure limits have improved and low and high temperature SCR NOx selectivity is also improving due to manufacturer development work.

Caterpillar commented that they agree with EPA’s assessment that the metal-CDPF technology has some potential to address some of the major questions concerning exhaust filters, but believes that the basic limitation of particulate reduction efficiency must be recognized, and thus efficiencies above 60% should not be assumed for metal-CDPF. They also noted that EPA stated that data from locomotive testing confirms relatively low elemental carbon fraction and relatively high organic fraction for PM emissions from medium-speed Tier 2 locomotive engines, and a system with an oxidation catalyst and a metal CDPF would reduce overall PM emissions from a locomotive or marine diesel by upwards of 90%. The commenter stated that, while true under some operating conditions on some engines, this does not recognize that the locomotive cycles which include operation at idle for 59.8% of the time for switchers and 38% for mainline. The commenter noted that the exhaust temperature is less than 260 °C for idle and throttle notches below 3 for medium-speed locomotives (as noted in EMA's comments on the ANPRM), and the efficiency of a metal-CDPF cannot be extrapolated to smaller high speed engines or to purpose built large marine engines.

Caterpillar also stated that using the high end of aftertreatment efficiency estimates as the generally achievable efficiency will lead to infeasible standards; and further that the metal-CDPFs have not been demonstrated in large size, and scale-up to large units is not trivial. The commenter stated that substantial lead time (several years) is needed to have units designed, built, and tested (and redesigned from field-testing knowledge, if necessary) to have any certainty that these units will function and survive in locomotive or marine applications with 9000 hp or more.

Letters:
Caterpillar OAR-2003-0190-0591.1
Electro-Motive Diesel, Inc. (EMD) OAR-2003-0190-0594.1
Engine Manufacturers Association (EMA) OAR-2003-0190-0575.1
General Electric Transportation (GE)OAR-2003-0190-0590.1
New Jersey Department of Environmental Protection (NJDEP) OAR-2003-0190-0562.2

Our Response:

We agree with EMD that the specific limitations of metallic filter technologies and issues with significant operation of locomotives under idling conditions cannot simply be "assumed away." Quite to the contrary, our Final RIA specifically considers the contribution of emissions from each of the locomotive operating modes (including idle operation) in evaluating the expected performance of a particular filter system. In a similar manner, our analysis in Chapter 4 of the RIA considers the impact of temperature at each locomotive operating mode on SCR NOx catalyst performance. That analysis along with testing conducted by EPA shows clearly that SCR catalysts can meet the 1.3 g/bhp-hr standard over the locomotive test cycle as we are requiring. The urea SCR durability data referred to by the commenter is the same data we analyzed in Chapter 4 of the RIA. There we show that urea SCR catalysts can provide acceptable NOx performance even following catalyst aging at temperatures in excess of the exhaust temperatures encountered even under the most severe line-haul locomotive operational conditions.

EPA has reviewed the studies cited by GE. In some instances, they are identical to studies cited by EPA within the Regulatory Impact Analysis and lead us to conclude that existing SCR technology could be used to meet the 1.3 g/bhp-hr standard at the end of locomotive useful life. We drew considerably different conclusions from these studies. These studies, and other studies both past and more recent, are cited in the both the Draft Regulatory Impact analysis and the Final Regulatory Impact Analysis, show very good NOx reduction efficiencies following hydrothermal aging and engine aging of zeolite-based SCR systems at 600 to 650 °C, which represent exhaust temperatures that are considerably higher than those encountered even under the most severe line-haul locomotive operation. Oil poisoning effects cited by the commenter were limited to catalyst poisoning by ZDP additives at the relatively high additization levels used with the much older American Petroleum Institute (API) CH-4 oil classification used with highway diesel engines in the U.S. and used by the researchers in the study. ZDP additives are not used in Locomotive Maintenance Officers Association (LMOA)-approved locomotive engine lubricants due to incompatibilities with engine bearing materials in some locomotive engines. It should also be noted that CH-4 and CI-4 highway diesel lubricants have been supplanted with CJ-4 lubricants for applications using exhaust catalysts. The newer CJ-4 lubricants, like the current LMOA locomotive lubricants, place restrictions on the zinc and phosphorous additives. In the case of the CJ-4 classification, the limitation placed on zinc and phosphorous additives were specifically added to prevent catalyst poisoning. Similar additive limitations were also placed on lubricating oil formulations for gasoline vehicles following the introduction of catalytic converters to prevent catalyst poisoning.

The issues regarding washcoat adhesion following high temperature aging with urea injection cited by the commenter also appear to be limited to light-duty automotive applications that see considerably higher exhaust temperatures than severe-service line-haul locomotives due to the placement of the SCR system upstream of the DPF system (rather than downstream, as expected with locomotive and marine applications) in order to meet transient cold-start NOx emissions control requirements. The upstream SCR location subjects the SCR system to temperature excursions of up to 800 °C during forced DPF regeneration, and the design also necessitates frequent forced DPF regeneration due to the absence of NOx for passive DPF regeneration. We do not expect this type of catalyst configuration to be used for locomotive (or marine) applications due to the very different operational characteristics of locomotives which are reflected through regulatory emission test cycles that differ radically between locomotives and light-duty diesel automobiles. The much longer 2000 hour aging interval cited by MECA in their comments and other durability data presented in the Regulatory Impact Analysis also points towards excellent catalyst durability at temperatures up to 600 °C for zeolite-based SCR systems. Recent data from EPA testing also shows low hour NOx efficiency for zeolite-based SCR to be considerably improved relative to either the commenter’s estimates of low-hour NOx performance and relative to EPA’s earlier estimates of low-hour NOx performance presented in the Draft Regulatory Impact Analysis. This testing confirms that the aftertreatment systems can maintain high efficiency at high hours.

GE’s comments referenced data in a manner that suggested that frequent changing of a locomotive diesel oxidation catalyst would be required over the life of a Tier 4 locomotive. The data cited showed hydrocarbon fouling of a DOC occurring due to fuel enrichment that was used during cold-start to rapidly heat a catalyst system configuration under development for a light-duty diesel vehicle platform. The commenter failed to note two important factors related to the observed hydrocarbon fouling in their review of the data:

1. Cold-start fuel enrichment for rapid catalyst heating will not needed to meet the Tier 4 locomotive standards since the standards do not require emissions to be measured during a cold start-up procedure as is the case with light-duty automobiles.
2. Even in the case of light-duty automobiles, the hydrocarbon fouling observed by the researchers was completely and nearly instantaneously reversible once the enrichment strategy was disengaged and the engine was returned to normal fuel management.
3. EPA testing confirms the ability to maintain $NO:NO_2$ oxidation at high hours and after exposure to high temperatures and high levels of lubricating oil contamination.

Regarding the EMD comments about exhaust backpressure, we have concluded that a properly-designed partial-flow DPF can provide less pressure variation as soot loading changes (between fully-clean and fully-loaded) than a wall-flow DPF. As discussed in Chapter 4 of the RIA, we believe that the PM standards are achievable using a partial-flow DPF, and expect that some marine and locomotive manufactures will choose partial-flow DPFs while others choose wall-flow DPFs. For wall flow-DPFs that require “active” regeneration, the effect of soot accumulation within the filter (and the resulting increase in exhaust backpressure) can be reduced by implementing a strategy of more-frequent regeneration events (i.e., regenerating the filter whenever there is an opportunity instead of waiting until the filter is fully loaded). For DPFs which rely on “passive regeneration”, where NO_2 created by the DOC is used to oxidize the soot, proper sizing of the DOC and selection of a proper washcoat formulation can assist in reducing backpressure variation. If the turbocharger design is matched to the worst-case backpressure scenario (a fully-loaded filter), compressor surge should not occur.

Concerning the comments from EMA and Caterpillar about the limitations of metal-CDPFs, our analysis of PM conversion efficiency at full useful life (detailed in section 4.3.1.2 of the Final RIA) – with no conversion expected in idle-Notch 1, 60% conversion in Notch 2, 85% conversion in Notches 3 and 4, and 83% conversion in Notches 5-8 – is comparable to the commenter’s analysis, with one exception. In Notch 2 operation, we use the exhaust gas temperature of 270 °C, which is supported in the 2005 AAR In-Use test data recorded on a Tier 2 GE locomotive. At 270 °C, we believe that a conversion efficiency of 60% in Notch 2 is possible, and a cycle-weighted, overall efficiency of 55% to 60% is feasible with a metal-CDPF. The 60% trapping efficiency takes into account only soot trapping, not oxidation of semi-volatile organic PM. Oxidation of semi-volatile organic PM contributes more to overall PM efficiency of a metal-CDPF for locomotive and category 2 marine applications due to the larger contribution of semi-volatile organic PM to total PM emissions.

EPA’s estimate of PM emissions was not only at specific operating conditions. The calculations of PM efficiency took into account the entire regulatory cycle (line-haul and switch for locomotives, E3 for marine) along with calculations of sulfate-make, soot trapping efficiency, and oxidation efficiency for semi-volatile organic compounds. For example, Figure 4-18 in the Draft Regulatory Impact Analysis showed calculated PM removal efficiency versus temperature for all eight loaded locomotive throttle notches and for operation at both idle conditions and dynamic brake conditions. As shown in the figure, the calculated PM removal drops to near zero at light load conditions below the light-off temperature of the semi-volatile organic species in the exhaust, which account for nearly all of the PM emissions for medium-speed engines at very low equivalence ratio/light load. PM removal efficiency also drops somewhat above 300 °C due to oxidation of fuel and lubricant sulfur over the PGM catalyst to form sulfate PM. The 90 % PM reduction for Tier 4 relative to Tier 2 includes a 50% reduction in engine-out PM going from Tier 2 to Tier 3, and then the application of catalytic controls for a cycle-average reduction of 60 to 70% when going from Tier 3 to Tier 4 technology.

The commenter's reference to engines in excess of 9000 hp is largely irrelevant. Current Tier 2 diesel electric locomotives in the U.S. do not exceed 4500 hp. Limited numbers of 6000 hp Tier 0 locomotives were produced in the past but are no longer offered. Marine engines above 9000 hp are nearly entirely Category 3 engines with cylinder displacements greater than 30 liters/cylinder. Among Category 2 marine engines produced and sold by Caterpillar, only the Tier 1 Caterpillar 3618 is over 9000 hp (9652 bhp rating). The Caterpillar C280-16 Category 2 marine engine has a continuous rating below 7200 bhp and the higher power Caterpillar/MAK M32C and M32CV marine engines exceed 30 liters/cylinder and thus are Category 3 engines that are not subject to the Tier 3 and Tier 4 standards.

After considering all of the issues specific to locomotive operation raised by the commenters, we continue to conclude that a Tier 4 PM emission standard of 0.03 g/bhp-hr and a Tier 4 NOx standard of 1.3 g/bhp-hr are feasible in the timeframe required by our final rule.

10.2.8 Size, Weight, and Packaging Concerns in Locomotive Applications

What Commenters Said:

AAR commented that the space available on a locomotive for DPF and SCR systems is extremely limited. The commenter noted that railroad tunnels, stations, and other features of the railroad right-of-way make it impossible to build wider locomotives, and longer locomotives would not be able to navigate the right-of-way. The commenter stated that it believes that the space available on locomotives today would not accommodate both a DPF and an SCR system, which are projected to take up more than 40 cubic feet. The commenter stated that weight is also a concern. The commenter noted that locomotives must be heavy enough for traction, but not so heavy as to damage track or cause derailments. AAR provided the example that hybrid line-haul locomotives likely will need smaller fuel tanks to reduce the weight of the fuel transported in the locomotives because of the weight of the batteries. The commenter noted that the aftertreatment devices contemplated by EPA are projected to weigh more than 8,000 pounds, and stated that it believes that weight could be problematic.

NJDEP commented that, with regard to the request for comment on the effect on locomotive weight and balance of DPF + SCR weighing 8,000 lbs with 40 cubic feet of volume when mounted above the engine, replacing the muffler provides the best location for placing the DPF + SCR systems without affecting the plane of locomotive weight distribution.

EMA noted that available space for aftertreatment in locomotives is severely constrained by engine and generator size and by the other necessary equipment that must be included to make a functioning locomotive. The commenter noted that a locomotive's outer dimensions are strictly constrained; the overall width and height and overall cross-sectional shape are limited by clearance requirements to pass under bridges and other structures, through tunnels, and next to trains on parallel tracks. The commenter noted that overall length is constrained by the need to keep clear of passing trains on curves. EMA further noted that operational requirements for switchers and lower-power main-line locomotives, such as minimum track radius for operation and track-per-axle weight limits, cause external size constraints to be even more restrictive than for the high-power 6-axle mainline locomotives. The commenter also stated that the difficulty of finding space for aftertreatment systems increases as locomotive power increases, due to the increasing aftertreatment size as engine power increases (the required aftertreatment size is approximately proportional to engine power). Additionally, the commenter stated, the cooling system requirements increase as engine power increases, which in turn causes the size of heat exchangers to increase as well.

EMA also commented that the aftertreatment size also depends on allowable backpressure. The commenter noted that the NPRM appeared to base some assumptions regarding aftertreatment systems on a simple scaling of aftertreatment size from on-highway applications. The commenter stated that it believes that this leads to an underestimation of the size of the aftertreatment systems needed for locomotive applications, as the backpressure allowed on large locomotive engines is less than on on-highway engines due to requirements to keep exhaust temperatures low to protect internal components. The commenter noted that component cooling is an increasing issue as component size increases. (E.g., the case of head cooling where, for a larger engine, the head deck must be made thicker to withstand the cylinder pressure as the bore size is increased. The thicker head deck makes cooling more challenging since the combustion surface temperature must be kept to the same limits.)

EMA further commented that locomotive weight is also constrained, axle loading is limited by rail capability, and bridge capacity is another overall constraint. The commenter stated that on-board storage of urea must recognize the inherent limits imposed by these fundamental weight constraints; the size and weight of the urea SCR system depends on the emission reduction required. The commenter stated that, in that regard, the NOx limits for locomotives should not be reduced below the levels set forth in the NPRM, since any additional stringencies would make an already difficult packaging task infeasible. The commenter stated that it does not believe that sufficient space exists in locomotives at current power ratings for the aftertreatment required to meet even the proposed limits. EMA commented that, overall, it remains concerned that the many difficulties involved in implementing aftertreatment requirements for locomotives have not been fully addressed.

EMA also commented that an additional major concern relates to the amount of urea that must be carried on-board. The commenter stated that requirements to store urea on-board in quantities significantly greater than the amount of urea needed to cover the total fuel usage on-board would seriously affect the practicality of deploying SCR. The commenter noted, for instance, that if future guidance documents required carrying enough urea to last until emission equipment service intervals, urea SCR would be completely infeasible. The commenter stated that in locomotive applications, for example, urea storage requirements to ensure that urea lasts until the 90-day inspection event would be excessive, requiring approximately 30,000 pounds of urea, greatly exceeding the additional weight that most locomotive designs could be expected to manage.

EMD commented that it retains significant concerns on size and weight of aftertreatment devices for NOx and particulate matter, and believes that EPA has underestimated their required size by half (and overestimated the space actually available on a locomotive). The commenter noted that tunnel operation poses significant challenges to aftertreatment devices, beyond simply operational temperature; and suggested that in EPA's tunnel tests the soot emissions from locomotives in tunnels should be evaluated. The commenter noted that the maximum height and width dimensions of locomotives are set by a modified AAR Plate "C," which limits locomotives to sixteen feet one inch high by ten feet eight inches wide. The commenter noted that freight cars that are taller than locomotives and are limited to certain routes, while a locomotive must be able to go everywhere on the system. The commenter also noted that the maximum length of a locomotive is limited to approximately eighty feet by curving considerations; longer locomotives overhang the track excessively on curves, and potentially can foul cars and locomotives on adjacent tracks. Lastly, the commenter noted that the weight of locomotives is limited by the maximum allowable axle load, with existing roadbed and bridge systems 35 tons per axle, or 420,000 pounds for a six-axle locomotive.

EMD commented that modern freight locomotives are up against all of these constraints. The commenter noted that increased power, and increased tractive effort due both to increased power and to improved wheel slip control, have necessitated sufficient extra structure in locomotives that meeting the 420,000 pound weight limitation is a challenge. EMD also commented that a locomotive has to carry its own fuel for its operational range. The commenter noted that a modern high-horsepower locomotive has a 5000 gallon fuel tank capacity, and fuel alone accounts for over 35,000 pounds of the locomotive's weight. The commenter further noted that the crew has to be able to pass between the locomotives in a multiple-unit consist, and has to be able to see along the units to monitor the train (for example to detect dragging equipment, shifted loads, or hotboxes), thus the walkways must be kept clear. Additionally, the commenter noted that the locomotive design has to allow space for maintenance (e.g., the space above the engine has to be kept clear to allow for in-service replacements of failed power assemblies) and for the crew and crew amenities, such as toilet facilities. The commenter raised the concern that much of the little space that might appear to be available on a locomotive is already taken up for other uses.

EMD commented that, in addition to the weight of aftertreatment devices, the weight of the structure to support them must be considered. The commenter stated that such devices would, of necessity, be mounted high in the locomotive, above the engine and exhaust turbo charger; but the engine and turbo charger are not designed to support several tons of machinery. The commenter stated that structure would have to be added to the locomotive to support aftertreatment reactors, and would have to be designed to withstand the longitudinal impact loads imposed by slack action in the train and hard coupling events, and the lateral accelerations imposed by rough track. The design criterion for such loads is five times the acceleration due to gravity. EMD commented that it is also concerned about the space required for any necessary reductant for NOx aftertreatment systems. The commenter noted that if, for instance, the reductant usage is five percent of the fuel use, space and weight allowance must be found for at least 250 gallons of reductant (otherwise, the use of fuel as reductant will reduce the locomotive's range).

EMD commented that it does not share EPA's confidence expressed in the NPRM that there is adequate space on our locomotives to package SCR and DPF components as presently envisioned. The commenter also noted that the available space on a locomotive is that occupied by the exhaust silencer (if one is fitted), and the other apparent space on the locomotive must be left empty to serve the maintenance and crew purposes described above. The commenter noted that the exhaust silencer occupies a volume of approximately 35 cubic feet, and the diesel particulate filter with which EMD has been carrying out early investigations has 47 cubic feet of elements alone, without accounting for necessary ductwork to lead exhaust from the engine to the elements, distribute the exhaust over the faces of the elements, and collect the filtered exhaust and lead it out of the locomotive or to the SCR reactor, for which there is no space once the DPF has been installed.

EMD commented that even the solution for a Tier 4 EMD 16-710G3C that EPA put forth, which utilizes exhaust manifold space to mount a diesel oxidation catalyst and uses a partial-flow DPF and an SCR reactor using a zeolite catalyst, does not meet the space requirements. The commenter stated that the total volume estimated by EPA to be required by the DPF and SCR is the 35 cubic feet available. The commenter noted that EPA has stated that there would be additional space required for the SCR dosing grid, urea mixing, for transitions between components, and for any elbows required for inertial separation and collection of ash from a partial-flow DPF; however, the commenter stated that for these latter items, there is no space on the locomotive. The commenter further stated that it believes that EPA's calculated space requirements appear to understate the actual case (see the table at OAR-2003-0190-0594.1, p. 20). The commenter noted that EPA's analysis cited the AAR Plate "L" clearance diagram, however, the commenter noted, locomotives meeting AAR Plate L are restricted from some areas of the North American railway system (such as notably the Northeast Corridor). The commenter noted that in order to be able to be used everywhere on the system, locomotives must meet a modified AAR Plate C clearance diagram. The commenter further noted that the Plate C clearance diagram requires locomotives to be notably narrower (ten feet eight inches versus eleven feet five and three quarters inches) and somewhat lower (sixteen feet one inch above top of rail versus sixteen feet three inches) than would be the case under Plate L. The commenter stated that locomotives therefore must occupy a smaller envelope than that assumed in EPA's analysis; and suggested that more analysis and discussion are required. The commenter further stated that, given the major concerns surrounding this issue, more discussion is warranted (than the one page in the DRIA).

Letters:
Association of American Railroads (AAR) OAR-2003-0190-0566.1
Electro-Motive Diesel, Inc. (EMD) OAR-2003-0190-0594.1
Engine Manufacturers Association (EMA) OAR-2003-0190-0575.1
New Jersey Department of Environmental Protection (NJDEP) OAR-2003-0190-0562.2

Our Response:

Our projection for catalyst/component volume was based on assigning a "reasonable" space velocity (one which provided a good balance between emissions reduction and exhaust backpressure) to each component – $120{,}000^{-hr}$ for the DOC, $60{,}000^{-hr}$ for the DPF, and $40{,}000^{-hr}$ for the SCR. In our analysis, we used engine data from AAR's locomotive in-use emissions test program to calculate the exhaust flow rate in units of "standard" cubic feet per minute (or SCFM, the conventional unit for volumetric flow used by catalyst manufacturers to calculate space velocity). In EMD's analysis, the "actual" exhaust flow rate was used instead of one corrected to "standard" flow conditions. For consistency in the evaluation and comparison of catalyst volumes, the actual exhaust flow rate of an engine is corrected to standard flow conditions. This method is the accepted practice in the catalyst industry, and is the appropriate method to use when sizing exhaust aftertreatment devices. EMD's method of analysis resulted in a flow rate which was approximately twice that of the value used in the EPA analysis, resulting in a space velocity which was two times greater as well. Once corrected to "standard" conditions, the commenter's results for space velocity (and by extension, component volume) are very close to the EPA analysis. Similarly, EMA notes that catalysts have been sized similar to truck engines which they conclude may be too small (too restrictive to exhaust flow) for locomotive applications. What EMA's comment fails to recognize is that the catalyst size in proportion to the locomotive exhaust flow is almost twice that of an on-highway truck. This is because the comparative sizing done by EMA is based on engine displacement (engine size) while exhaust flowrates are determined by a combination of engine size, intake boost pressure and engine speed. Because rated speed for on-highway truck engines are about twice that of locomotive diesels, the actual volumetric flowrate of a locomotive engine after considering the size difference is about half of that of a truck. Hence, the exhaust backpressure predicted based on on-highway trucks is much higher than what we would project for locomotive engines given their lower volumetric flowrate for the same engine displacement.

The EPA analysis of packaging, described in 4.3.3 of the RIA, is predicated on all aftertreatment components and associated hardware fitting within the AAR Plate "L" profile for locomotives and equipment. Our analysis, as well as a complete system design done by a major exhaust system integrator (Tenneco Automotive), shows that there is adequate space/clearance available in today's 4400-HP Tier 2 locomotives, and indicates that the technologies needed to meet the aftertreatment-forcing Tier 4 standards can be packaged in future locomotives. Since the EPA packaging analysis did not utilize the width available in Plate L – and the height above the top rail is only 2 inches shorter – the dimensional differences between Plates L and C do not have a significant impact on the outcome of our analysis. Our analysis of the packaging did not assume that urea storage tank(s) or aftertreatment components would encroach on existing walkways or crew areas. Furthermore, our analysis (detailed in the Chapter 4 of the RIA) shows that the space above the engine can accommodate the packaging volume necessary for the projected Tier 4 emissions systems. While placement of aftertreatment devices within this space may require some changes to current maintenance practices, it should not require their complete removal to accommodate power assembly replacement.

While existing turbochargers and locomotive hoods may not be designed for "structural" loads (in the sense that they can support the weight of aftertreatment devices), they can be re-designed – or structures can be added - to support such loads. Concerning onboard reductant, we are not requiring that locomotives be designed to maintain any specific amount of urea onboard. Manufacturers will be free to design urea systems to have refill intervals appropriate for the market. However, we expect that the most likely approach will be design the urea systems to need refilling at the same schedule as the fuel tanks. Since a 32.5% urea/water solution weighs approximately 9 lbs/gal, and 250 gallons (5% of the typical fuel capacity of a line-haul locomotive), this amount of urea solution would weigh approximately 2,250 lbs. We believe the weight increase due to onboard reductant, component re-designs, and aftertreatment support structures will not cause a locomotive to exceed the 420,000 lb. weight limitation. The additional weight due to installation of aftertreatment components can be mitigated through the use of computer-aided design techniques to minimize the weight of supporting structures and by taking advantage of weight savings elsewhere in the locomotive through the use of lighter-weight materials in place of steel.

EPA does not agree that the only space available for packaging aftertreatment components is the silencer, or that the space above the engine must be left completely open (as it is today) for maintenance purposes. As described in 4.3.3 of the RIA, and shown in Tenneco's aftertreatment system design (RIA Chapter 4, Figure 4-21), there is space above the engine (a trapezoidal cross-section) that can be utilized for aftertreatment components while preserving the clearance needed to facilitate power assembly removal. We believe that adequate space exists above the engine to accommodate the necessary components and preserve the "maintainability" of the engine.

Partial-flow DPFs should not require inertial separation/collection hardware – accumulated ash can migrate through the device and pass through the SCR catalyst.

10.3 Tier 3 and Tier 4 Marine Standards

10.3.1 Lead-Time for Marine

What Commenters Said:

EMA commented that it believes that the proposal compresses the lead time and stability periods for the proposed standards to the very limit of feasibility, and so establishes the earliest possible effective dates for imposing Tier 3 and Tier 4 requirements on marine engines. The commenter further noted that it believes that, in certain respects, the NPRM provides what in other circumstances would clearly amount to insufficient lead time. The commenter pointed to MECA's public hearing testimony noting that MECA confirmed that the workloads facing engine and aftertreatment system manufacturers, together with the time that is necessarily involved in transferring emissions technologies from one industry segment to another, preclude the deployment of aftertreatment systems for marine engines until 2015 at the earliest. EMA commented that it believes that it is thus clear (and confirmed by third-party experts) that any tightening of the proposed implementation dates for the Tier 3 and Tier 4 standards would necessarily result in an infeasible and therefore non-implementable rulemaking. The commenter further stated that it is concerned that the proposed regulatory framework and implementation dates threaten to cross over the boundary of feasibility in setting the timing of the standards that will apply to certain locomotive engines. EMA also requested that EPA clarify that the proposed engine repower requirements - the requirement to use current tier engines when repowering an existing vessel - will not carry over to Tier 4 engines. The commenter noted that aftertreatment systems anticipated for Tier 4 engines (including large DPFs, SCR systems, exhaust extensions and piping, plus necessary urea tanks and packaging equipment) cannot be retrofitted into existing vessels without incurring extreme and disproportionate redesign and reconstruction costs.

Letters:

Engine Manufacturers Association (EMA)	OAR-2003-0190-0545, 0575.1

Our Response:

We have worked extensively with the Engine Manufacturers Association, its members, and a range of marine industry stakeholders to develop a Tier 3/Tier 4 marine emissions control program that gets the maximum achievable emission reductions possible giving appropriate consideration to the lead time necessary for manufacturers to introduce this new technology. In general, we have not changed the implementation dates for Tier 3 and Tier 4 marine engines from those that EMA commented on at the proposal. However, EMA's comments – and our discussions with them – did result in one significant change that we have made with regard to some of the largest marine engines above 2,000 kW rated power. In that particular case, we have decided to advance the start date for the Tier 4 NOx program to 2014 while at the same time eliminating the Tier 3 NOx control step for these same engines. As described in section 3 of the preamble, this will allow for a significant improvement in air quality sooner while simplifying the development timeline for these engines. The elimination of the Tier 3 NOx control step will provide manufacturers with adequate time to develop and introduce the Tier 4 NOx control step in 2014.

We agree with commenters that raised concerns regarding the application of Tier 4 emission standards to existing vessels. Under our proposed program if the owner of an existing vessel chooses to repower with a new engine, we would have generally required that the new engine meet the latest emissions standards up to and including the Tier 4 standards. Giving consideration to the fixed design of existing vessels and our expectations that Tier 4 emissions control systems will need to be considered within the vessel design, we have concluded that it would not generally be possible to repower existing vessels with Tier 4 engines. We are therefore finalizing an approach as described in section IV.C of the preamble to the final rule that would allow the repowering of existing vessels with previous Tier engine systems.

10.3.2 Stringency of Marine Standards

What Commenters Said:

EMA commented that engine manufacturers agree with and support EPA's conclusion that Tier 4 standards, if adopted, should be limited to large commercial marine applications. The commenter stated that the relevant vessel design and engine installation constraints make it infeasible or extremely impractical to install aftertreatment systems in recreational or smaller commercial marine vessels. The commenter noted that in reaching the overall conclusion regarding the inherent constraints on the application of aftertreatment systems to marine engines, it previously developed a series of matrices to identify those types of marine vessels where aftertreatment might be feasible. EMA noted that the matrices (see Appendix A, OAR-2003-0190-0577.1) list the critical characteristics that marine engine manufacturers must account for when considering the use of aftertreatment systems, such as urea SCR systems or DPFs. The commenter noted that the critical characteristics evaluated in the matrices stem from engine manufacturers' knowledge of vessel types, installations, and usage. The commenter also noted that there are no vertically integrated manufacturers in the marine industry, therefore, the commenter suggested that for various items covered in the matrices, it is recommended that EPA seek additional information from the other key stakeholders impacted by this rulemaking, including vessel designers, builders, owners, and operators.

Letters:

Engine Manufacturers Association (EMA)	OAR-2003-0190-0577.1

Our Response:

We received comments regarding our proposal to limit the application of the Tier 4 emission control technologies to commercial engines above 600 kW and recreational above 2,000 kW (see section 3.2.1.2 of this Summary and Analysis of Comments document). Some commenters, such as EMA, concurred with our analysis showing that choosing such a power cutpoint for the application of Tier 4 was an appropriate way to address the numerous technical challenges to the application of Tier 4 emission control systems to small vessels. Other commenters, most notably State and environmental organizations, argued that the Tier 4 standards should apply to marine engines as small as 25 hp. While we agree that even small diesel engines as little as 25 hp can be designed to work with Tier 4 emission control technologies as is required under our Nonroad Tier 4 program, we do not have the same confidence that these systems can be applied to vessels that incorporate water cooled exhaust systems, high power to weight ratios, water injection systems and other unique aspects of marine vessel design as described in Chapter 4 of the RIA and discussed in section 3.2 of this document. Therefore as we explain in section III of the preamble, we have decided to finalize the 600 kW commercial marine cutpoint for Tier 4 engines just as we proposed.

In a change from our proposal, we are not extending the Tier 4 program to recreational marine diesel engines. In our proposal we indicated that at least some recreational vessels, those with engines above 2000 kW (2760 hp), have the space and design layout conducive to aftertreatment-based controls and professional crews who oversee engine operation and maintenance. This suggested that aftertreatment-based standards would be feasible for these larger recreational engines. While commenters on the proposal did not disagree with these views, they pointed out these very large recreational vessels often travel outside the United States, and, for tax reasons, flag outside the U.S. as well. Commenters argued that applying Tier 4 standards to large recreational marine diesel engines would further discourage U.S.-flagging because vessels with those engines would be limited to using only those foreign ports that make ULSD and reductant for NOx aftertreatment available at recreational docking facilities, limiting their use and also hurting the vessel’s resale value.

In general, we expect ULSD to become widely available worldwide, which would help reduce these concerns. However, there are areas such as Latin America and parts of the Caribbean that currently do not plan to require this fuel. Even in countries where ULSD is available for highway vehicles but not mandated for other mobile sources, recreational marinas may choose to not make ULSD and reductant available if demand is limited to a small number of vessels, especially if the storage and dispensing costs are high. To the extent the fuel requirements for Tier 4 engines encourage vessel owners to flag outside the United States, the results would be increased emissions since the international standards for these engines are equivalent to EPA’s Tier 1 standards.

After considering the above, we conclude that it is appropriate at this time to hold recreational marine diesel engines to the Tier 3 standards. We plan to revisit this decision when we consider the broader questions of the application of our national marine diesel engine standards to engines on foreign vessels that enter U.S. ports in the context of our Category 3 marine diesel engine rulemaking.

10.3.3 Technology Transfer to Marine From Other Sectors

What Commenters Said:

EMA noted that emission control technologies for marine engines are derived from other nonroad engine applications, which in turn are derived from on-highway applications. The commenter noted that at each link of this technology transfer, the increasing complexities of machines and operating environments pose major obstacles to any wholesale transfer of advanced emission control systems, and therefore necessarily prevent a one-to-one transfer of the upstream emission standards. EMA also suggested that EPA ensure that the final rule accounts for any requirements that classification societies (e.g., U.S. Coast Guard, American Bureau of Shipping (ABS), etc.) may establish with respect to the exhaust aftertreatment systems that are expected to be deployed in marine vessels for Tier 4 compliance. The commenter noted that when those requirements are developed, the stringency, costs, and overall impacts on the design and manufacture of marine engines and vessels of the proposed Tier 4 standards may need to be adjusted. EMA suggested that EPA engage in additional outreach efforts with all key stakeholders in finalizing the rule.

MECA commented that it strongly believes that many of the emission control technologies and strategies that are either in or nearing commercial use for meeting the Tier 2 light-duty diesel vehicles standards, or are commercialized or under development to meet the Tier 4 nonroad diesel standards will be applicable to locomotive and marine diesel engines in the 2015 timeframe to meet the proposed Tier 4 locomotive and marine diesel emission standards. MECA also noted that SCR technology using a urea-based reductant has been safely installed on a variety of marine applications in Europe since the mid-1990s on engines ranging from approximately 450 to over 10,000 kW. The Port Authority of New York and New Jersey has recently conducted a pilot project to demonstrate diesel emissions reduction technologies on a ferry retrofitted with DOC+SCR systems on its two main, four-stroke propulsion engines. The commenter noted that emissions testing showed NOx reductions that typically exceeded 94% during ferry cruise modes. The commenter stated that it believes that this project, and other operational marine SCR installations, provides firm evidence that SCR systems can be engineered to meet rigorous marine industry safety standards. The commenter further noted that some of these marine SCR systems have been operating since the 1990s with no reported safety-related issues. MECA commented that as discussed in the EPA technical feasibility document, SCR catalyst 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 composition. Base metal zeolite SCR catalysts, in particular, are being developed for applications that require NOx performance and durability under higher exhaust operating temperatures that may be encountered in some mobile source applications. Recent results, published by engineers from Ford Motor Co. at the SAE 2007 World Congress (SAE 2007-01-1575) detail performance characteristics of base metal zeolite SCR catalysts under consideration for mobile source applications on cars and trucks. The zeolite SCR catalysts in this study maintaine1d peak NOx conversion efficiencies of more than 90% over a broad inlet exhaust gas temperature window after hydrothermal aging in a simulated diesel exhaust for 64 hours at 670°C. For low temperature NOx conversion efficiency, emission control system design engineers have a number of options available including the composition of the SCR catalyst itself, 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.

Caterpillar commented that it agrees that NOx aftertreatment using SCR has been demonstrated sufficiently to apply to many marine applications at some point, based on strictly technical considerations of engine and aftertreatment issues. The commenter also stated that it agrees that NOx reductions of up to 80% are feasible under limited conditions. The commenter stated that it does however have concerns about the details of applying this technology from an engine/aftertreatment system standpoint, and from the requirement of applying these in a variety of applications. The commenter stated that it believes that SCR is not viable in all cases from a vessel builder or operator standpoint; noting that even after extensive redesign, many vessels will not be able to provide the additional space or to accommodate the additional weight without seriously compromising vessel capabilities. The commenter stated that, fundamentally, requirements to keep the exhaust flow at acceptable temperatures to the SCR inlet will be challenging and may not prove to be feasible in all cases. The commenter suggested that EPA should reach out to vessel builders and architects to help provide this assessment.

The Passenger Vessel Association (PVA) commented that Tier 4 emission reductions are based on land-based technology that has not yet been shown to be adaptable to the rigors of some types of marine service. The commenter stated that it believes that the total operating experience for post-combustion emissions control in the marine environment is very limited and not yet supportive of the optimism reflected in the Tier 4 timelines in the NPRM.

Letters:
Caterpillar OAR-2001-0190-0591.1
Engine Manufacturers Association (EMA) OAR-2003-0190-0575.1, 0545
Manufacturers of Emission Controls Association (MECA) OAR-2003-0190-0494, 572.1
Passenger Vessel Association (PVA) OAR-2003-0190-0576.1

Our Response:

As EMA’s comments note, we have worked with EMA and others in the marine industry in considering these factors before making our proposal to set the stringency and implementation dates of the Tier 3 and Tier 4 locomotive and marine standards. Subsequent to our proposal, we have continued to meet with representatives of the various marine industry stakeholder groups in order to ensure that concerns of all stakeholders are considered. As explained in sections III and IV of the preamble, we have made a number of changes and clarifications in the final rulemaking to address the concerns of these groups, including the use of Tier 4 engines for vessel repower, and the procedure that we will use when considering issues of vessel safety and engine design. We appreciate EMA’s recommendation that we have extensive outreach with all members of the marine community, and we have followed through on that recommendation.

Regarding EMA's suggestion that the final rule account for any future requirements that classification societies establish with respect to exhaust aftertreatment devices, the Agency cannot anticipate what those requirements may be, but is prepared to deal with them as they arise.

We received numerous comments showing that advanced Tier 4 emission control technologies have been successfully applied in specific marine applications throughout the world. The comments also shared specific issues with these applications for example with regard to operation under low exhaust temperature conditions. We have used this information in our evaluation of the Tier 4 technologies detailed in Chapter 4 of the RIA including our analysis of performance under operating conditions above and below the range of appropriate application for urea SCR based NOx control.

There has been considerable experience with post-combustion emission control systems in the marine environment, particularly in Europe. To date, we are aware of 390 engine installations of SCR that have been installed into 95 marine vessels. For the 2007 calendar year, 4 additional vessels with 22 engines have been scheduled for installation of SCR aftertreatment systems (see Docket ID EPA-HQ-OAR-2003-0190-0737). The number of vessels which are currently using (or will soon be using) SCR technology indicates these emission control systems are adaptable to the rigors of a marine environment.

10.3.4 Long-Term Durability of Marine Aftertreatment Technologies

What Commenters Said:

The City of Vallejo, Baylink Ferries urged EPA to reconsider the reliability, durability, and cost factors for the use of diesel exhaust aftertreatment (SCR) as a means to achieve Tier 4 standards. The commenter noted that the City of Vallejo operates the M/V SOLANO, the only high-speed passenger ferry with SCR installed. The commenter urged EPA to consider the information in the report attached to its comments (OAR-2003-0190-0581.1) and to visit the SOLANO for the purpose of gaining a better understanding of how these systems have performed, and how these systems will impact the vessels.

Letters:	
City of Vallejo, Baylink Ferries	OAR-2003-0190-0581

Our Response:

The commenter provided a detailed report summarizing a myriad of significant technical issues experienced on the M/V SOLANO - a high-speed passenger ferry with a urea SCR catalyst system installed. While the SOLANO report documents that urea SCR catalysts can be highly effective at controlling NOx emissions on a marine application, and that it is possible to package a large catalyst based emission control system on a high power to weight ratio vessel like a high speed ferry, it also highlights a number of shortcomings of this particular installation. Specifically, the report shows that the SOLANO has experienced significant failures of the catalyst mounting system due to corrosion and subsequent structural collapse. The experience of the SOLANO project certainly serves as a cautionary tale regarding the application of new technology with limited lead time and reflects the experience that unfortunately some early adopters of technology occasionally realize. We have reviewed the SOLANO experience and considered it in our overall review of the appropriateness of applying Tier 4 emission control technologies to marine applications. In aggregate, it leads us to continue to conclude that Tier 4 technologies can provide dramatic emission reductions in marine applications and that emission standards predicated on the application of these technologies should occur in the 2014 or later timeframe required in our final rule.

10.3.5 Expected Performance of Marine Aftertreatment Technologies

What Commenters Said:

With regard to the statement in the NPRM that passive regeneration occurs at 250°C, GE commented that it believes that effective passive regeneration depends on a number of parameters, but generally requires considerably higher temperatures (approximately 400°C) for catalyzed filters. The commenter noted that, for marine applications, reliable regeneration must always occur and there is little room for error for occasional failed regenerations. The commenter stated that it believes that the lower temperature of 250°C for regeneration that EPA cited is the temperature at which regeneration may occur under the correct circumstances (depending on NO_2 content, soot quantity, and soot distribution), but it is not the temperature required to ensure reliable regeneration for the wide variety of marine engine types at issue. The commenter stated that active regeneration can be achieved by using burners to heat the exhaust when soot has accumulated. The commenter noted that this could result in exhaust temperatures of approximately 1200 °F (650°C) going up the entire exhaust stack, a substantial increase from the current stack temperatures of approximately 850°F (450°C) or lower, and will require extreme care in the design of the stack and insulation system. The commenter further stated that this results in the need for more care in installations and maintenance of exhaust systems than is the case with current vessels.

EMA commented that the use of DPFs in marine applications remains unproven, and is perhaps the core issue relating to the feasibility of the NPRM. The commenter stated that, unlike SCR aftertreatment systems, particulate filter systems for marine engines have not been tested in marine vessels except for a very few publicly-funded demonstration projects in very limited and tightly controlled applications. EMA commented that it thus believes that significant questions remain to be answered concerning the use of particulate filters with marine engines.

The Overseas Shipholding Group, Inc. (OSG) commented that it supports the efforts to reduce emissions from ships, but the commenter raised the concern that the proposed regulations rely on the application of technologies that are not yet developed for the marine environment.

The commenter noted that deliveries of new OSG U.S.-flag vessels stretch to 2012 and it is not clear how the ship building and engine manufacturing industries will meet the requirements.

MECA commented that SCR catalyst performance and durability issues are generally independent of the diesel engine application under consideration. The commenter stated that catalyst performance will be largely a function of inlet exhaust gas conditions of temperature and gas composition, the space velocity that the catalyst operates at, the composition of the catalyst, the levels of potential poisons present in the exhaust stream, and the maximum temperature that the catalyst is exposed to during the full useful life period. The commenter further stated that it believes that these catalyst boundary conditions, although not completely equivalent between locomotive and marine diesel engines, are within the performance windows of existing SCR catalyst formulations.

Letters:

Engine Manufacturers Association (EMA)	OAR-2003-0190-0545
General Electric Transportation (GE)	OAR-2003-0190-0590.1
Manufacturers of Emission Controls Association (MECA)	OAR-2003-0190-572.1
Overseas Shipholding Group (OSG)	OAR-2003-0190-0589.1

Our Response:

Several commenters raised issues concerning the application of DPF technologies to marine engines. We believe that there is sufficient lead-time to adequately develop both partial-flow and wall-flow DPFs for marine applications. The challenges facing marine applications of this technology are similar to the challenges that are being addressed for nonroad engines of which many of the marine engines are derivative designs. We see nothing in the design or operational characteristics of marine engines that would cause us to believe that DPFs cannot be used in these applications. The challenge of applying catalytic PM controls to marine vessels is also taken into account within the schedule for implementation and within the stringency of the Tier 4 PM standards. Note that the lead time for Tier 4 contemplates these vessel-specific issues (including the timing of existing orders) and is addressed in greater detail in section 10.2.1, above.

10.3.6 Size, Weight, and Packaging Concerns in Marine Applications

What Commenters Said:

OSG commented that it believes that EPA should recognize the specific issues related to the marine environment. The commenter stated that new designs must account for the installation of aftertreatment equipment considering that space in the stack is limited and additional weight in the vessel has an impact on trim and stability, particularly for retrofit applications where it may not be feasible to install aftertreatment technologies such as scrubbers or SCR.

Argillon LLC commented that it believes that packaging of these systems in the confined areas available will be extremely challenging but is considered to be possible.

EMA commented that it believes that the requirement for urea storage should not exceed the amount required to cover the fuel that is carried on-board, with some modest margin, which suggests an amount this is just slightly above what is necessary to cover the maximum diesel fuel storage capacity of the vessel—essentially, that urea would need to be available at virtually all marine diesel fuel tank filling locations.

EMA also commented that it has concerns about the details of applying this technology to a wide variety of marine applications, as it does not believe that many vessel types will be able to provide the necessary room for SCR systems or account for their additional weight. The commenter further stated that the requirements to keep the SCR inlet exhaust gas temperatures within acceptable ranges will be challenging and may not prove to be feasible in all cases, and SCR systems may have adverse impacts on certain types of vessel decking and hulls. The commenter specifically noted that vessel alloys containing copper are a key area of concern, since urea can dissolve copper even when copper is contained in an alloy. EMA urged EPA to reach out to vessel designers and naval architects to obtain proper feedback regarding those vessel types where it is most probable that SCR systems can be utilized effectively.

Lastly, EMA commented that marine vessels below certain size ranges or outside of standard-power commercial applications lack the necessary space and design flexibilities to accommodate advanced exhaust aftertreatment systems. The commenter noted that systems currently envisioned for marine applications could be as large as the marine engines themselves, and likely will require additional tanks, piping and packaging equipment, all of which will impose very significant space and weight impacts on vessel builders.

PVA commented that one of its primary concerns is Tier 4 wherein the engine will be but one part of the total power installation. The commenter noted that the emission control and aftertreatment of Tier 4 could double or triple the space and weight of considerations during build or rebuild of the vessel. The commenter further noted that in the high speed ferry sector where there is foreseeable growth during this time, weight and volume can be large problems to overcome in design, operating costs, and engine efficiency. The commenter stated that external emissions equipment also brings about maintenance and repair concerns not currently encountered. PVA also commented that it believes that existing high speed ferry/passenger vessels should be permanently capped at a maximum of Tier 3 when repowering. The commenter noted that the current-generation high speed vessels rely on high power, lightweight, managed weight distribution, hull design, and judicious space allocation to achieve speed and economy of operation. The commenter further commented that the addition of large weights and volumetric concerns associated with SCR and DPF in existing hulls is difficult and probably not accomplished without substantial performance degrades such as trim, horsepower, revenue space and weight, shoreline erosion, and economic viability. PVA provided the example that the addition of SCR technology to reduce NOx 50% on one of three sister vessels demonstrated that maintaining speed required an increase in horsepower, higher fuel consumption, the addition of 4 tons of SCR related weight, substantial cost, and the degradation of the operating envelope (trim by the stern, larger wake, and slower acceleration).

The Elliot Bay Design Group commented that for most existing vessels, the Tier 4 requirements of adding the particulate filters and SCRs and the necessary modifications to make them fit would increase the vessel's weight and vertical center of gravity, compromising the vessel's stability. The commenter stated that, as many older vessels are already operating with minimal stability margins, it is concerned that extra equipment may create unsafe operating conditions.

Letters:

Argillon LLC	OAR-2003-0515
Elliott Bay Design Group	OAR-2003-0190-0486
Engine Manufacturers Association (EMA)	OAR-2003-0190-0545
Overseas Shipholding Group, Inc. (OSG)	OAR-2003-0190-0589.1
Passenger Vessel Association (PVA)	OAR-2003-0190-0507

Our Response:

Several commenters raised concerns about the effect that added weight (due to installation of aftertreatment technologies) will have on vessel performance. We did not propose – nor are we finalizing – a standard which requires the installation of Tier 4 technologies on existing vessels (i.e., the packaging of Tier 4 aftertreatment components is only a concern for new vessel designs). For Tier 4 vessels, the effect of that weight, packaging, and placement of these components will have on vessel performance (e.g., trim, stability, fuel consumption, power requirements, wake, etc.) can be accounted for by the marine architects when designing new vessels. For vessels slated for engine replacement (repower), they will not be required to install Tier 4 engines and their related aftertreatment components – they are only required to install a Tier 3 engine (or a Tier 2 engine, if installing a Tier 3 engine is not feasible). Urea- or reductant-based SCR technology will only be required on new vessels equipped with Tier 4 engines. Based on our discussions with marine architects and review of existing marine SCR retrofit applications, we do believe that new vessels can be designed to accommodate the maintenance, repair, and extra weight of these components, as well as the urea storage and delivery systems. If these new vessels utilize urea-SCR technology, they can be built using appropriate alloys/material for the urea storage and delivery systems.

Concerning urea storage capacity, we expect that storage capacity will reflect the duty cycle and regional characteristics of the area in which a particular type of vessel is expected to operate (i.e., a vessel intended to operate out of ports near major cities could refill with urea at each fuel stop, whereas a vessel operating from a remote port would need greater urea storage capacity).

While stationary powerplant (and some of the early ferry) applications have utilized large volume/low-cell density SCR catalysts to minimize the backpressure increase (or match the backpressure of the existing engine), we expect the new Tier 4 engines and systems will be designed to accommodate more-compact components. These “compact” aftertreatment components can be sized similar to the engine displacement-to-catalyst volume ratios found in the on-highway and nonroad engine designs on which they are based. As discussed in 4.3.3 of the RIA, we expect the volume required DPF and SCR components will be 1.7 and 2.5 times an engine’s total volumetric (cylinder) displacement, respectively.

10.3.7 Vessel Safety

What Commenters Said:

Tidewater Inc. commented that it is also concerned that the addition of exhaust emission treatment equipment into existing vessels’ engine rooms and stack spaces, especially if associated with catalytic converters that may require additional heating, may have acute safety considerations. The commenter noted that engineering spaces, even in current designs, are crowded with equipment. The commenter stated that it believes that any modifications that impact accessibility of areas within these spaces could detrimentally affect a vessel’s ability to extinguish a fire, and/or hazard crewmembers’ lives. The commenter urged that consideration in any proposed rules reflect these implicit dangers, as a fire at sea is a deadly serious matter.

Tidewater also noted that a greater concern for the marine industry and commercial marine vessel operations generally, is the belief that the rules focus on the engines to the exclusion of every other factor including the safety of the vessel and seafarers. The commenter stated that in the past, the older non-electrically controlled engines were robust enough to get the vessel back to port. The commenter stated that today’s electronic engines are more temperamental, require factory technicians to repair, and can leave vessels stranded. The commenter stated that it believes that adding complex emissions equipment will further strain limited crew capabilities and extend work hours. The commenter stated that the NPRM will require additional equipment, piping and storage tanks adding weight and creating stability concerns—which can be addressed in new vessel designs, but the impacts and costs are not understood by the engine manufacturers and are not common to the land-based locomotive industry.

OMSA noted that the preamble states offshore vessels are quite diverse and place a high premium on engine reliability, considering the potentially serious ramifications of engine failure underway (72 FR 15974). The commenter noted that offshore vessels tend to operate from remote locations with limited crew size. The commenter stated that no regulations should be implemented that increases the danger of fire, capsize, or critical system failure. The commenter stated that it believes that the engine exhaust rules proposed will provide a benefit to numerous people; however, prior to implementation of the new standards, the commenter urged EPA to analyze and consider any increase in the risk to life of the mariners operating offshore support vessels. The commenter stressed that EPA cannot increase the risk of one population to benefit another. OMSA urged EPA to study the reliability of marinized designs, the availability of ULSD and urea to the marine market and effect of Tier 3, and Tier 4 ancillary systems on vessel design and operations prior to implementing the standards on vessels.

EMA commented that in the specific case of marine engines, the inherent constraints and demands of the marine environment present very unique and significant challenges. Those challenges, the commenter stated, include the requirements for extreme engine power density in order to bring vessels up to plane or to tow or push heavily loaded ships and barges, the utilization of wet exhaust systems and the resultant potential for sea water contamination, and the especially important requirements for safe and durable operation at sea (which dictate, among other things, very strict limits on the surface temperature of engine and exhaust systems).

EMA also commented that the issue of higher exhaust stack temperatures must be addressed and resolved with due regard to the various extremely sensitive applications that are found in-use, such as vessels that service off-shore drilling platforms. The commenter noted that while EMA does not anticipate that there will prove to be any inherent problems in the integration of aftertreatment systems into commercial vessels powered by engines greater than 600 kW, the possibility of having higher surface temperatures near at hand must be considered, as there may be some specific applications where high exhaust stack temperatures are simply not acceptable. The commenter suggested that provisions may be needed in the final rule to allow vessel owners to apply for an exemption from the Tier 4 aftertreatment-forcing standards for certain sensitive applications where a hazardous environment may be present, such as for those vessels that are classified as Class 1, Division 1 under the rules of the National Fire Protection Association (NFPA). The commenter further suggested that EPA should engage in further outreach efforts with the NFPA and other key stakeholder groups concerned with vessel safety to address this issue.

GE commented that it believes that another issue is the potential overheating of a filter due to carbon build-up and the subsequent oxidation of excessive carbon, or a regeneration with insufficient exhaust flow, which can lead to melting of the filter. The commenter stated that this can cause significant backpressure, which in turn can seriously reduce the power of the engine. The commenter stated that it believes that, due to the extremely high temperatures at issue, there is a potential for burning through the outer surface of the reactor, which could lead to large exhaust leaks and hot outer surfaces. The commenter stated that it is concerned that these issues have not been addressed (nor resolved) for marine applications, and should be a concern for vessel designers, operators, and those that will certify these aftertreatment systems.

EMD commented that it believes that it is paramount to keep in mind that marine applications are very unforgiving. The commenter noted that loss of, or significant restriction in, power is extremely serious in a marine application. The commenter provided the examples that: vessels must be able to be positioned properly to survive large waves in storms; harbor tugs must not suffer power restrictions or the large vessels they are pushing or pulling may not be able to be controlled; Mississippi and Ohio River systems vessels must have enough power to keep a line of up to 24 barges positioned in a curving channel while avoiding bridges and other traffic;

and Great Lakes freighters must be able to run upstream against the current in the Detroit River in a channel that is narrower than the vessel is long. EMD stated that insufficient power to overcome the current would cause extreme difficulties for any maneuvering.

Marathon Petroleum Company LLC commented that it supports EPA's goals of reducing engine emissions in a cost-effective and technologically feasible manner. However, the commenter stated that it believes that it is important for EPA to consider that although engine technology may be developed to lower emissions, it is critical that the technology be able to be marinized and used on vessels while maintaining safety and operational efficiency standards. Marathon commented that it is specifically concerned about the application of aftertreatment-based technology. The commenter stressed the importance of giving consideration to issues like below deck area for installation of aftertreatment technology and the availability of aftertreatment technology chemicals and maintenance facilities. Because of the equipment requirements for Tier 4 technology, the commenter stated, Tier 4 engines should only be required on vessels that are built after the effective date of the Tier 4 standards.

Caterpillar commented that particulate filters continue to be a large unknown for marine applications. The commenter noted that these systems have not been tested in marine applications except for very few units in very limited applications. The commenter noted that EMA's comments on the ANPRM two years ago documented many of these concerns. Caterpillar commented that it believes that EPA has not adequately addressed many of these serious obstacles to applying particulate filters in marine applications, as noted below:

a) Particulate filters can experience filter plugging—they can accumulate soot and create excessive backpressure if regeneration does not occur on a regular basis. Excessive backpressure can substantially reduce the power the engine can produce, thus a reliable regeneration must be available for filters with the potential for plugging to be used in marine and locomotive applications.

b) A loss or significant restriction in power is extremely serious in a marine application: in storms, vessels must be able to be positioned properly to survive large waves; harbor tugs must not suffer power restrictions or the large vessels they are pushing may not be able to be controlled; vessels on the Mississippi river system must have enough power to keep a line of 24 or more barges positioned in the curving channel while avoiding bridges and other traffic; Great Lakes freighters must be able to run upstream against the current in rivers in a channel that is narrower than the vessel is long, insufficient power to overcome the current would cause extreme difficulties for any maneuvering.

c) The commenter noted that EPA has stated that passive regeneration will occur at 250 °C and commented that it believes that effective passive regeneration depends on a number of parameters, but generally requires considerably higher temperature (approximately 400 °C) for catalyzed filters. The commenter also noted that fuel sulfur and lubricating oil ash can degrade the catalyst over time, and that, for marine applications, reliable regeneration must always occur. The commenter stated that there is little room for error for occasional failed regenerations, and raised the concern that the lower temperature of 250 °C for regeneration is the temperature that regeneration may occur under the correct circumstances (NO_2 content, soot quantity, soot distribution), but is not the temperature for reliable regeneration for a variety of engine types.

d) Active regeneration can be achieved by using burners to heat the exhaust when soot has accumulated, resulting in exhaust temperatures of approximately 1200 °F (650 °C). This exhaust going up the entire stack will be near this temperature, and is a substantial increase from current stack temperatures (approximately 850 °F (450 °C) or lower); thus requiring extreme care in the design of the stack and insulation system. This installation and maintenance will need to be done with even more importance than on current vessels.

e) Filter overheating due to carbon build up and subsequent oxidation of excessive carbon, or the regeneration with insufficient exhaust flow, can lead to temperature excursions and melting of the filter. Thus causing significant backpressure which can seriously reduce the power of the engine, also due to the extremely high temperatures the potential exists for burning through of outer surface of the reactor, which could lead to large exhaust leaks and hot outer surfaces. All issues which have yet to be addressed for marine applications. The issue of higher exhaust stack temperatures needs to be addressed from the standpoint of use on extremely sensitive applications such as drilling vessels. The possibility of having a more generally combustible environment near exhaust systems must be considered, as there may be applications where high exhaust stack temperatures are simply not acceptable. Provisions may be needed to exclude certain applications entirely from the aftertreatment requirement.

Caterpillar also commented that, in light of the above concerns, it would certainly participate in and support any future EPA-led review to address whether particulate filters can be successfully applied to marine applications.

Letters:

Caterpillar	OAR-2003-0190-0591.1
Electro-Motive Diesel, Inc. (EMD)	OAR-2003-0190-0594.1
Engine Manufacturers Association (EMA)	OAR-2003-0190-0575.1
General Electric Transportation (GE)	OAR-2003-0190-0590.1
Marathon Petroleum Company	OAR-2003-0190-0595.1
Offshore Marine Services Association (OMSA)	OAR-2003-0190-0611.1
Tidewater Inc.	OAR-2003-0190-0557

Our Response:

Several commenters raised the issue of a potential for increased component and exhaust stack temperatures that may occur with the use exhaust aftertreatment technologies. Many comments focused on the DPF, expressing concern that the exhaust temperature increase which occurs during normal soot regeneration and/or un-controlled soot regeneration events will affect vessel safety. While the 650 °C exhaust temperature stated by the commenter for soot regeneration of a DPF may be higher than what is observed on existing engine installations, it is not beyond the temperature observed in nonroad and on-highway engines using DPF technologies. We believe the existing methods for meeting the vessel classification requirements for marine engine component surface temperatures can also be utilized to manage the expected temperature increase due to DPF soot regeneration. In particular, we expect that the heat shielding materials and design practices employed on today's marine diesel engines in flame- and heat-sensitive environments will be used on Tier 4 applications as well (see RIA Chapter 4, section 4.3.2 for an example of exhaust manifold heat shield blankets applied directly to exhaust manifolds). Currently, several 2007 model year, on-highway trucks equipped with DPFs and active soot-regeneration strategies manage the temperature increase of DPF soot regeneration with air-cooled heat shields on the tailpipe. We believe other technologies, such as air-gap construction, or air-gap construction with an outer water jacket, could be used to keep surface temperature below required levels. We believe the knowledge and experience in gained by manufacturers in the areas of temperature management, soot regeneration controls, and reliability of DPFs will directly apply to marine engines.

Also of concern to one commenter was the perception that a migration from non-electronic to electronic engine controls was detrimental to vessel reliability. EPA believes that electronic controls are indeed reliable, as evidenced by the millions of miles accumulated by similar heavy-duty, on-highway trucks utilizing them. The commenter did not cite any study or data indicating that electronically-controlled engines are less-reliable than their predecessors. In fact, EPA believes that electronic engine controls can provide engine manufacturers and vessel operators with increased reliability (in that the diagnostic capabilities and engine control flexibilities inherent in electronic control systems can alert the operator of potential concerns).

While we acknowledge that uncontrolled soot regeneration can result in overheating of the filter, we point out that the probability of this occurrence is rare, and can be mitigated through proper calibration, control, and monitoring of the DPF. Again, it is the experience gained from use of DPFs in on-highway and nonroad applications that leads us to conclude that this technology is reliable today, and will only be more so in the future as millions of hours are accumulated on these devices prior to their implementation in the marine and rail sectors. If engine manufacturers and vessel builders determine that the uncontrolled regenerations and reactor burn-through are a risk – regardless of the application – system monitoring and engine control strategies can be employed to minimize the probability of such an occurrence and reduce the severity of a system failure, should one occur.

We do not expect that engine reliability and power for marine vessels will be compromised by the use of Tier 4 technologies. The commenter does not suggest how engine operating conditions and/or operating environments for marine diesel engines is more-severe than those founds in nonroad applications. Information to date from on-highway applications – both in the United States and, to a greater extent, in Europe – suggest that a properly designed and maintained DPF is a safe and reliable technology for reducing PM emissions. As engine manufacturers gain experience in challenging nonroad DPF applications, we expect this knowledge will result in reliable aftertreatment and engine control systems for the rail and marine industries that employ these technologies.

Concerning Caterpillar's comments, we believe that considering the available NOx to PM ratio of Tier 4 engines and the temperatures encountered, that there will be sufficient opportunity for passive regeneration that would prevent soot accumulation from occurring within the filter to an extent that would result in filter plugging. Given our experience with this technology and the transfer of technologies between sectors, we also believe that PM filters - when developed and implemented with consideration given to experience gained in other sectors - will be reliable, safe, and not cause unexpected exhaust restriction and loss of power. There is no suggestion that these filter technologies (and the experience gained from their application in other sectors) cannot be safely transferred to the marine sector. Engine manufacturers will have experience in the operational characteristics and reliability of these devices prior to their use in marine engines. The 400 °C temperature cited is for extruded vanadium wall-flow filters that are tolerant of fuel sulfur levels higher than that of ULSD. The 250 °C temperature was based on data cited within the RIA for operation using ULSD fuel and passive regeneration of trapped PM using NO_2 generated via oxidation of NO emission over platinum group metal (PGM) catalysts; either upstream of the DPF, coated to the DPF, or both upstream and coated. We do not expect the need for frequent active regeneration for these applications due to their NOx to PM ratio, the exhaust temperatures available during operation under load and the operation of the engines using ULSD. We do not expect carbon build-up to exceed DPF PM capacity due to the increased opportunity for passive regeneration for these applications.

10.4 Other

10.4.1 Aftertreatment Technology Demonstrations in Other Countries

What Commenters Said:

SCAQMD commented that it concurs with EPA's assessment that the proposed Tier 4 standard is technologically feasible. (The commenter cited the Draft RIA, p.4-32, "If no improvements were made to technologies which exists today, the 1.3 g/bhp-hr locomotive standard is technologically feasible.") The commenter noted that it has consulted with and visited several entities that have retrofitted or are ordering new locomotives (and marine vessels) with aftertreatment control devices. The commenter noted specifically Swiss Rail and Hug Engineering, one of the leading manufacturers of aftertreatment control devices. The commenter noted that Swiss Rail has gained enough experience with diesel particulate filters that it is ordering 73 new 2000 Hp diesel locomotives with fully integrated diesel particulate filters, and Swiss Rail plans to replace all of its existing diesel powered locomotives with new locomotives equipped with DPFs. The commenter further noted that Swiss Rail representatives also indicated that they have tested a smaller railyard locomotive with a combined DPF/SCR system. The commenter noted that Miratech, Hug Engineering's U.S. distributor, is currently conducting locomotive retrofit demonstrations for EPA and SCAQMD. The commenter stated that Hug's modular design approach could allow aftertreatment devices to be installed in a variety of configurations, which would help address space constraints. The commenter further noted that Hug has also integrated a DPF system into a planned 3500 hp line-haul locomotive, thus showing that such retrofits are possible. Additionally, SCAQMD noted that other manufacturers have begun work on designing aftertreatment devices into new and existing locomotives.

SCAQMD commented that it understands that there may be a fuel consumption penalty associated with the locomotive DPF, but noted (based on data regarding the use of DPFs in European locomotives) that the penalty will be no more than 1-2 percent provided the backpressure limitations are met. The commenter stated that it strongly believes that early field demonstrations of control technologies provide valuable opportunities for manufacturers to refine their products. (The commenter noted that it is also sponsoring two field demonstrations of SCR/diesel particulate filter technologies on passenger trains, applicable to both switch and line-haul locomotives.) The commenter noted that they - as well as CARB - are continuing discussions with locomotive manufacturers on demonstration projects that could result in locomotives with advanced aftertreatment controls in the 2010 to 2012 timeframe. Specifically, the commenter noted, the SCAQMD and CARB staffs recently discussed a potential project to demonstrate SCR technologies on Class I line-haul locomotives as a second phase to the passenger locomotive demonstration project.

AAR commented that at the public hearings, SCAQMD referred to locomotives in Europe equipped with DPFs, arguing the technology already exists for locomotives in the U.S. The commenter noted that Hug Engineering DPFs have been installed on 2000 hp horsepower switching locomotives operating in Switzerland, and one Hug DPF has been installed on a prototype 3600 horsepower locomotive, however CARB reports that there will be no locomotive models produced following the development of this prototype. The commenter stated that the U.S. should take advantage of lessons learned in Europe. However, as CARB observed, the fact that DPFs are being used on low-horsepower Swiss locomotives does not mean that the technology is ready to be installed on higher-horsepower line-haul locomotives in the U.S. The commenter specifically noted that only synthetic engine lube oil (low ash) can be used in the Swiss locomotives (the commenter stated that its understanding is that only the Swiss use synthetic oil in locomotive applications, which makes their locomotives unique in Europe and in the world). The commenter further noted that low sulfur diesel fuel (LSD) in Switzerland has a sulfur content around 300 ppm, but LSD in the U.S. is fuel with a sulfur content of up to 500 ppm. AAR lastly noted that Swiss railroads have no DPF maintenance responsibility until the manufacturer’s warranty expires; and in-service DPF exhaust emissions testing has not yet been performed (and is not planned).

EMD suggested that EPA should not rely too strongly on European experience to support the feasibility of the Tier 4 standards. The commenter acknowledged that there have been several applications of diesel particulate filtration and SCR in European locomotives. However, the commenter noted, European locomotive operation is very different from that in the United States. The commenter stated that North American locomotive operation is much more severe than that in Europe—for example, the bulk of locomotives fitted with diesel particulate filters in Europe are Swiss shunting locomotives (“switchers”, in American lexicon) and not subject to heavy operation even by European standards. EMD commented that there is one heavy haul locomotive in existence with a DPF, and it has seen only limited service and the manufacturer has no plans to build more. The commenter noted that in both this locomotive and the shunters, the engine takes up much less of the total space within the locomotive than in American locomotives, so packaging of aftertreatment components is relatively easier. The commenter urged that EPA recognize that projection of European results to the United States is an uncertain proposition at best; and it further stated that success in Europe does not lend much support to the feasibility of U.S. standards forcing aftertreatment.

MECA noted that it has received data from one of its member companies currently offering zeolite-based catalysts for sale in Europe for truck applications and developing zeolite-based catalysts for U.S. 2010 heavy-duty applications. The commenter stated that this data indicates that a zeolite-based catalyst maintains approximately 90% NOx conversion efficiency in a simulated diesel exhaust stream at exhaust temperatures ranging between 250 and 550 °C after hydrothermally aging the catalyst (in an air stream containing 10% water vapor and 20 ppm SO_2) for up to 2000 hours at 600 °C. The commenter stated that no degradation in NOx conversion efficiency in the 250-550 °C inlet exhaust temperature range was observed between fresh and aged catalysts. MECA also noted that its European affiliate association, Association of Emissions Control by Catalyst (AECC, www.aecc.be), recently completed a heavy-duty Euro VI demonstration program on a modern, low-NOx U.S. 2007-class diesel engine (7.5 liter engine displacement). In this program, an advanced diesel emission control system including a DOC + catalyst-based DPF (14 liter filter volume) and a urea-SCR zeolite-based catalyst (14 liter catalyst volume) + ammonia slip catalyst was evaluated for emissions performance following 200 hours of oven aging of the catalyst components at 600 °C. The commenter stated that over the European Steady-State Cycle (ESC), this aged system reduced NOx emissions by approximately 85% and PM mass emissions by more than 90%.

MECA further noted other studies and laboratory evaluations on zeolite-based SCR catalysts in its comments. The commenter stated that the performance of zeolite-based SCR catalysts is not expected to be impacted by operating in a locomotive or marine diesel exhaust that contains a 0.03 g/bhp-hr PM level (the proposed Tier 4 PM standard for these engines). The commenter referred to Fe-zeolite SCR catalysts which have recently been commercialized in Japan for heavy-duty truck applications. These applications combine a DOC placed in front of an SCR catalyst and operate with PM levels (at the SCR catalyst inlet) which are considerably higher than 0.03 g/bhp-hr with no reported problems.

Letters:
Association of American Railroads (AAR) OAR-2003-0190-0566.1
Electro-Motive Diesel, Inc. (EMD) OAR-2003-0190-0502, 0594.1
Manufacturers of Emission Controls Association (MECA) OAR-2003-0190-572.1
South Coast Air Quality Management District (SCAQMD) OAR-2003-0190-0483, 0558.1

Our Response:

While we acknowledge the concern of some commenters that aftertreatment technology demonstrations in Europe are not identical to the duty-cycle and/or operating conditions experienced in U.S. locomotive or marine operations, we do believe that these demonstrations serve to illustrate the emissions-reducing capability of DPF and SCR technologies. The Hug Engineering DPFs are a different technology than the DPF systems described in Chapter 4 of the RIA. The system is designed to operate at considerably higher fuel sulfur levels than the ULSD used for Tier 4, and thus the systems are designed to rely primarily on active soot regeneration using a fuel burner system. EPA staff met with representatives of Hug Engineering in May 2007 (see docket EPA-HQ-OAR-003-0190). Our understanding based on our meeting is that there are approximately 300 to 400 locomotives in Switzerland (operated by SBB, The Swiss Railway) equipped with 550 kW engines and Hug PM filters used for maintenance, construction and light switching operations. There are another 100 switch locomotives equipped with 1.5 MW Caterpillar 3512 engines and Hug PM filters. Some of these units have accumulated 15,000 hours of operation without needing ash maintenance. There is one additional short-haul locomotive equipped with a 2.7 MW engine and a Hug PM filter. Hug also has experience installing exhaust aftertreatment in marine applications up to 14.5 MW and stationary power applications up to 40 MW. Although the European experience with using PM filters on locomotives represents operation and equipment that differs from what is used in North America, it still represents an important base of knowledge that can be built upon as we progress towards implementation of the Tier 4 standards. There is much that can be learned from SBB and Hug with regards to in-use operational experience, catalyst packaging, substrate mounting and maintenance of the systems.

Our assessment of feasibility is based primarily upon an assessment of U.S. Tier 2 locomotives and U.S. locomotive operation, along with an assessment of catalytic PM and NOx control systems under development for the U.S., Europe and Japan for highway, nonroad, marine and locomotive applications (see Chapter 4 of the RIA for a discussion on the feasibility of the Tier 4 emission standards).

10.4.2 NOx Sensor Technology

What Commenters Said:

GE commented that NOx sensors currently available are not sufficiently accurate or reliable for locomotive applications. The commenter stated that data supplied by a NOx sensor manufacturer showed a degradation in performance over time that would drive NOx higher than acceptable limits. The commenter claimed that a significant technological invention – not just a breakthrough with existing technology – would be required to develop a NOx sensor capable of maintaining NOx levels within EPA guidelines over the useful life of the locomotive, with acceptable cost and with maintenance intervals that coincide with the needs of locomotive service.

GE also commented that NOx sensor sensitivity has a crucial role to play in the capability of a closed loop control system and estimated that even to achieve a 1.9 g/bhp-hr NOx level, current NOx sensors would require substantial improvement in sensitivity, selectivity, and resolution. The commenter stated that interference from ammonia on the NOx sensor can force the system to operate in a non-optimum manner, resulting in increased NOx or increased ammonia slip (or both). In addition, GE posed the following questions related to NOx sensor accuracy and the resultant conversion efficiency of the system:

- is a reliable NOx sensor, with 5% accuracy, available to control urea dosing sufficiently and achieve 95% NOx conversion when using a Zeolite-based SCR when not kinetically limited?
- is 5% of point the limit of point the limit of NOx sensor accuracy?
- does NOx sensor accuracy currently limit NOx conversion efficiency of feedback controlled SCR systems, and if so by how much?
- what level of NOx conversion efficiency using a Zeolite-based SCR when not kinetically limited is achievable using current feedback control systems using of zirconia-NOx sensors?
- what level of NOx conversion efficiency can be expected taking into consideration projected NOx sensor and feedback control system development over the next ten to fifteen years?"

GE further commented that the Siemens/VDO Smart NOx sensor is an advanced zirconia-based, multilayer, state-of-the art NOx sensor with 3 oxygen pumps, the accuracy of which is quoted at +/- 10%. GE stated that this sensor's accuracy limits NOx conversion efficiency for two reasons; 1) an error in NOx sensor reading in the feedback control system drives error in the dosing of the urea system, which either underdoses the system, resulting in poorer NOx conversion, or overdoses the system, resulting in greater ammonia slip, and 2) the inability of the zirconia NOx sensor to distinguish between NOx and ammonia (NH_3). The commenter stated that a system which has been overdosed with ammonia due to error in the NOx sensor reading will read the higher ammonia slip as additional NOx, and then may increase the ammonia dose, rather than decrease it, as is necessary for proper control – and that this propagation of error in the feedback control system makes the control system inherently unstable. Also, they stated that as the system goes out of control, the error compounds, rather than being limited to the single inaccuracy. The commenter also stated that the accuracy of NOx sensors is not expected to improve to be better than +/-5% (today's sensors have an accuracy of +/-10%, so reaching this entitlement by sensor manufacturers is a significant technical challenge). The commenter noted that closed loop control systems do enable system optimization around a point that minimizes a combined NOx/NH_3 output – and that absolute accuracy of the sensor is not required to find this minimum point – but without an absolute measurement, the minimum point does not assure compliance.

EMA commented that the durability of NOx sensors – a potential tool which can be used to detect urea quality – remains a key unresolved issue. The commenter stated that if a NOx sensor is used to determine urea quality, it is highly questionable whether an unanticipated NOx reading could be related solely to urea quality.

MECA noted that NOx sensors are commercially available and have been used on light-duty vehicle applications of lean-burn, gasoline direct injection engines to control NOx adsorber-based catalysts by some manufacturers. The commenter noted that NOx sensors are also under development by other manufacturers for applications on both highway and nonroad diesel engines to control catalyst-based NOx emission control systems and to provide diagnostic information concerning the performance of these systems. The commenter further stated that it expects suitable NOx sensors to be available for use on locomotives and marine diesel engines in time for Tier 4 applications.

NJDEP provided comments on EPA's request for feedback regarding NOx sensor accuracy requirements. NJDEP responded that the NGK/Siemens development target is 2% accuracy for new NOx sensors and 5% aged accuracy by 2014. NOx sensor control systems improve NH_3 metering systems by modulating feed proportional to engine-out NOx and consequently raising net mobile engine NOx performance incrementally above 95% by approaching 1:1 NH_3/NOx ratios and by lessening NH_3 bypass levels to below 5 ppm.

Letters:
Engine Manufacturers Association (EMA) OAR-2003-0190-0575.1
General Electric Transportation (GE)OAR-2003-0190-0590.1
Manufacturers of Emission Controls Association (MECA) OAR-2003-0190-572.1
New Jersey Department of Environmental Protection (NJDEP) OAR-2003-0190-0562.2

Our Response:

Several comments raised concerns about the durability and accuracy of NOx sensors, as relates to their use in control of urea- or reductant-based SCR systems. EPA has examined these concerns (also detailed in 4.3.5.1 of the Final RIA) and we believe that today's commercially-available NOx sensors are capable of meeting the accuracy and durability requirements necessary to achieve the Tier 4 locomotive and marine NOx standards. Concerning durability, EPA acknowledges that a NOx sensor's output may drift over time (at high mileage/hours), but control algorithms exist which compensate for sensor drift and assure control system accuracy as these components age. Several heavy-duty truck manufacturers have indicated that they will be applying today's NOx sensor technology to their 2010 products for control of urea dosing and aftertreatment system diagnostics. In addition, they state that they expect these sensors will be durable for the full useful life of the engine (will not be replaced as a scheduled service replacement part).

With respect to sensor accuracy, we believe that the Tier 4 standards are achievable with the current specification of +/- 10%. Since the primary function of the NOx sensor, when used for closed-loop control of urea dosing, is to provide feedback to the control system control as it strives to minimize the post-SCR NOx levels, the absolute accuracy of the sensor (in terms of the actual NOx ppm level present in the exhaust stream) is not significant. To ensure compliance with the NOx standard, EPA expects manufacturers will have a thorough understanding of their engine-out emissions in both the new and full useful life conditions. We do not anticipate that manufacturers will use NOx sensor output as a means of ensuring compliance with the standard.

10.4.3 Ammonia Slip

What Commenters Said:

EMD noted that, in both the locomotive and marine proposed regulations, EPA included language which is boilerplate in previous rules, preventing a locomotive or marine engine from emitting a noxious or toxic substance that it would otherwise not emit and that would contribute to an unreasonable risk to public health, welfare, and safety. The commenter stated that EPA should recognize that emissions of ammonia from NOx aftertreatment systems, "ammonia slip," will be inevitable in engines using SCR to meet the proposed Tier 4 standards, particularly during transients. The commenter noted that ammonia is a noxious gas toxic in high concentrations, detectable by the human olfactory system at concentrations between five and fifty parts per million. The commenter requested that EPA structure these paragraphs not to disallow emissions of ammonia at technically feasible levels; the commenter believes that if EPA fails to do so, manufacturers may be left with no way to meet the Tier 4 standards.

AAR commented that the railroads, along with locomotive manufacturers, also are concerned about the issue of ammonia slip. The commenter noted that the railroads cannot afford for there to be noxious ammonia fumes, as this would be an issue both for their employees and the communities in which they operate. The commenter stated that not only are ammonia fumes unpleasant, but the smelling of ammonia raises safety concerns that are not present elsewhere, such as in the trucking industry. The commenter noted that the railroads annually transport approximately 40,000 carloads of anhydrous ammonia, a toxic-by-inhalation hazardous material. AAR commented that if an employee or some other person smells ammonia from an SCR system in a rail yard, they might mistake the smell for anhydrous ammonia, resulting in evacuations, the disruption of rail services, and, perhaps, other adverse consequences.

GE commented that its calculations show that transient ammonia slip levels could reach around 50 ppm and steady-state levels are expected to be in excess of 10 ppm. The commenter stated that decreasing urea dosing levels to control the ammonia slip level will necessarily lead to increased NOx levels. The commenter further stated that even if an aftertreatment system can be built to perform with low ammonia slip under new, ideal conditions, that same system will inherently produce significant ammonia discharges as the system degrades and under transient engine operation as ammonia is stored and released on the catalyst. The commenter stated that it believes that the issue is maintaining low ammonia slip while still meeting a 1.3 g/bhp-hr NOx level. GE commented that it implemented a closed-loop control strategy into Monte Carlo models for catalyst system performance. The commenter stated that it is possible to ensure that ammonia slip levels stay within reasonable limits, but there is a tradeoff - an increase in NOx emissions. The commenter noted that, depending on the ammonia slip requirements, the dosing ratio of NH_3/NOx needs to be adjusted. GE commented that, at lower ammonia slip requirements, lower dosing ratios are required to meet these limits, which in turn results in lower SCR conversion and higher NOx emissions. The commenter requested that EPA acknowledge that ammonia slip emissions at steady state up to 25 ppm, and 100 ppm for transient operation, not be considered to violate the prohibition of proposed §1033.115(c). GE stated that EPA's rules mandate a design which leads to these slip levels, so it would be inappropriate (and arbitrary and capricious under CAA § 307(d)) to establish a rule that requires violation of one provision in order to satisfy another.

NJDEP provided comments on EPA's request for feedback on what level of ammonia slip is achievable from modern urea-SCR systems using closed-loop feedback control, and whether or not 5 ppm is an appropriate level to set for maximum ammonia slip under any conditions. The commenter stated that less than 10 ppm bypass with 95+% SCR NOx reduction is achieved under long term durability in mobile applications with older NOx sensor technology. 99% SCR NOx reduction has been achieved with 3 ppm NH_3 bypass. The commenter stated that both are achieved with key benefits provided by NOx sensor control of closed-loop NH_3 metering technology and thorough reductant mixing and uniform well dispersed flow through the SCR catalyst. NJDEP also commented that the 5 ppm NH_3 bypass limit is judged to be appropriate. The commenter stated that this will serve to sustain investment in continued NOx sensor technology development to control NH_3 bypass to below 5 ppm, which in turn places less reliance on NH_3 bypass catalytic oxidation clean-up (a selective technology also known for NOx reformation and N_2O emissions, a global warming gas).

NJDEP also provided comments regarding the feasibility of achieving low ammonia slip (bypass less than 5 ppm) from urea-based systems that dose at 1:1 NH_3/NOx ratio under extreme engine out 500-600 ppm NOx in steady state and transient load conditions. The commenter stated that low NH_3 by-pass at 1:1 NH_3/NOx feed ratio is feasible. The commenter noted that current mobile source systems achieve 95% NOx reduction with less than 10 ppm NH_3 bypass, and stationary engines achieve 99% NOx reduction with less than 3 ppm NH_3 bypass. The commenter stated that the combination of precise ammonia metering, two NOx sensors functioning in closed-loop feed-forward and feed-back control, and thorough mixing with uniform flow concentration through the SCR unit make less than 5 ppm NH_3 a feasible target.

Letters:

Association of American Railroads (AAR)	OAR-2003-0190-0566.1
Electro-Motive Diesel, Inc. (EMD)	OAR-2003-0190-0594.1
General Electric Transportation (GE)	OAR-2003-0190-0590.1
New Jersey Department of Environmental Protection (NJDEP)	OAR-2003-0190-0562.2

Our Response:

See also our responses in 10.4.2 (NOx Sensor Technology).

The issue of NH_3 emissions (or ammonia slip) was raised by several commenters, with claims that excessive NH_3 emissions are "inevitable", and may reach 50 ppm during steady-state operation. We have assessed this issue and concluded that a properly-designed slip catalyst, with good selectivity to nitrogen (N_2), can convert most of the excess NH_3 released from the SCR catalyst into N_2 and water. Recent studies by Johnson Matthey and the Association for Emissions Control by Catalyst (AECC) have shown that an aged SCR system equipped with a slip catalyst can achieve tailpipe NH_3 levels of less of than 10 ppm when tested on the European Stationary Cycle (ESC) and European Transient Cycle (ETC). EPA testing over a simulated locomotive duty cycle confirms very low NH_3 slip at very high NO_x conversion when using an appropriately designed slip catalyst with high selectivity (see Chapter 4 of our RIA). The SCR system in the Johnson Matthey study was aged on a cycle which included 400 hours of high-temperature operation at 650 °C (to simulate active DPF regeneration events). Our analysis of the locomotive engine operating conditions presumes a maximum, post-turbine exhaust temperature of 560 °C. This presumption is based on implementation of a "passive" DPF regeneration approach (in which NO_2 created by the oxidation catalyst is sufficient to oxidize trapped soot) and our own testing of locomotives during consist operation in non-ventilated tunnels. Under these conditions, we expect slip catalysts to be durable and effective in reducing NH_3 slip.

In Chapter 4 of the RIA, we also describe how ammonia slip can remain low at high NOx reduction efficiency even with relatively high NOx feedgas rates through the use of static mixers, closed-loop urea dosing and the use of a highly selective ammonia slip catalyst. Data published by Englehard (a catalyst manufacturer) and DAF (a European truck manufacturer) at the SAE 2006 World Congress (SAE 2006-01-0640) showed emissions results obtained using an ammonia slip catalyst configured into a hydrothermally-aged SCR catalyst system operated at high space velocities. The data showed that greater than 90% NOx removal could be achieved with less than 25 ppm of ammonia slip even at excessive dosing rates of greater than 1.3:1 and with NOx feedgas concentrations higher than those of Tier 2 locomotives. More moderate dosing rates near 1:1 resulted in peak ammonia slip of 6 ppm or less.[3] Recent engine tests conducted by EPA also showed similar results of very low ammonia slip and high conversion at high engine-out NOx concentrations comparable to those of a Tier 2 GE locomotive (see docket EPA-HQ-OAR-2003-0190).

Compact urea-SCR systems that have been developed to meet the U.S. 2010 heavy-duty truck standards use closed-loop controls that continuously monitor NO_x reduction performance. Such systems have the capability to control stack emissions of NH_3 to below 5 ppm during transient operation even without the use of an ammonia slip catalyst. We understand that such systems may still emit some very small level of uncontrolled pollutants and we would not generally consider a system that releases de minimis amounts of NH_3 or nitrous oxide (N_2O) while employing technology consistent with limiting these emissions to be in violation of §1033.115(c) – which is the same way we currently treat passenger cars and heavy-duty trucks with regard to N_2O and hydrogen sulfide (H_2S) emissions.

It also should be clear that the levels of slip which we believe could be experienced in the exhaust stack (<25 ppm) would be rapidly diluted by ambient air at a ratio well in excess of 1000:1, leading to ammonia levels near a Tier 4 locomotive or marine vessel which are well below levels detectable through smell (to an observer standing near, or operating, a locomotive or marine vessel). In addition, when locomotives are operating in railyards under low power or idle conditions, the exhaust temperatures are too low to support hydrolysis, and no urea dosing will occur. Similarly, for locomotive operation inside maintenance facilities, low power settings or battery power can be used to move the units without activating urea dosing system. Hence, we believe that AAR's concerns with regard to ammonia smells and false alarms at railyards are addressed with the systems we expect locomotive builders to apply.

10.4.4 Urea Infrastructure and On-Board Storage

What Commenters Said:

EMA commented that it is concerned that urea will not always be available for marine vessels when operating outside of the U.S. The commenter noted that when vessels return to the U.S. after extended operation in foreign waters, their urea supplies may have been depleted. The commenter noted that urea availability for locomotives and marine vessels will depend on significant infrastructure investment, and urged that the effective dates for the proposed Tier 4 standards need to take this into account. EMA stated that it believes adequate lead time is included in the NPRM to allow for infrastructure development, but it cannot be assumed that the infrastructure will be fully developed in all cases. The commenter further noted that a vessel cannot be limited in power when urea is not available, as engine power is needed for safe maneuvering and cannot be reduced. EMA commented that it believes that any reporting or recording procedures relating to urea use and quality should not be overly complex or burdensome.

EMA also commented that Tier 4 locomotives will require NOx control, which will likely include an SCR system and a ready supply of urea. The commenter stated that since urea is known to freeze at approximately -12°C (11°F), SCR systems that are exposed to extended low ambient temperatures will require some type of onboard heating elements or coolant flow systems to maintain sufficiently high urea temperatures during operation. EMA commented that it does not believe this will present a major technical challenge for most marine applications. The commenter noted that commercial marine engines generally operate in ambient conditions above urea-freeze temperatures, and likely will have internally mounted and protected urea tanks and injection systems which can be thermally managed. (The exception to this would be with respect to deck-mounted marine engines.) The commenter noted that locomotive engines can often operate in below urea-freeze temperatures—exposed tanks, lines, and pumps will be difficult to control thermally and special precautions, or even cold weather packages, may be required for certain line-haul and especially switcher locomotives. The commenter stated that, in the case of extended shutdown periods in frigid conditions, including days or weeks at a time, the only practical way to thaw the frozen urea will be through the use of heated engine coolant circulated around or through the urea tank. The commenter further stated that, as the main urea tank(s) are likely to be mounted externally, near the diesel fuel tanks, it will be especially challenging to thaw the tank after extended shutdown. An internal urea day tank may be mounted, which can be thawed electrically after engine(s) restart, but there will be some period of time in which urea flow will be inhibited and the SCR system will not be effective.

EMA further commented that main urea tanks on locomotives are expected to be between 7% and 10% of the on-board diesel fuel tanks, equating to a 350-500 gallon urea tank for a Tier 4 mainline locomotive, and a 100-200 gallon tank for a Tier 4 switcher locomotive. The commenter provided a table on the needed heat outputs for raising the temperature of these tanks from -20 °F to +15 °F (EPA-HQ-OAR-2003-0190-0575.1, p. 51). The commenter noted that, considering that an 85 amp alternator will be used for heating, and the heating elements operate at 90% efficiency, it can be anticipated that the urea tanks will take between 4 and 16 hours to thaw, not including the energy required to heat all lines and pumps to move urea to the point of injection. The commenter stated that a smaller internally-mounted day tank, which is expected to supply urea for the minimum 4 hours of operation, will have to be sized between 20 and 100 gallons, depending on whether the locomotive engages in switcher or mainline operation; the commenter stated that the most feasible way to thaw these smaller day tanks over the same 35 °F temperature rise is to use electrical elements, and provided a table with the necessary power requirements (OAR-2003-0190-0575.1, p. 52). The commenter noted that the time required to thaw the day tanks (assuming an 85 amp alternator and 90% efficiency elements) is expected to take up to 220 minutes, during which the SCR system will not be fully operational from either the main tank or the day tank, depending on day tank size. EMA stated that it thus believes that a 4-hour thaw period will need to be included in the final rule as an extended emissions compliance exclusion period for locomotives that experience extreme cold weather start-up conditions.

EMA commented that urea availability for locomotives and marine vessels will depend on significant infrastructure investment, and further stated that the effective dates for the proposed Tier 4 standards need to take this into account. The commenter stated that it believes adequate lead time is included in the NPRM to allow for infrastructure development, but it cannot be assumed that the infrastructure will be fully developed in all cases.

Caterpillar commented that an additional concern is how much urea must be carried on board. The commenter noted that, to cover the total fuel usage on board, urea storage requirements would be significantly greater than the amount that could be carried; and the commenter believes that this could seriously affect the practicality of urea SCR. The commenter requested that the on-board urea storage requirements be kept reasonable to keep urea SCR technology as a feasible approach; the commenter further stated that it believes that the requirements for urea storage should not exceed that required to cover the fuel that is carried with some modest margin. The commenter suggested that the urea storage capacity should be no more than 115% of that to cover the on-board fuel capacity.

Letters:

Caterpillar	OAR-2003-0190-0594.1
Engine Manufacturers Association (EMA)	OAR-2003-0190-0575.1, 0545

Our Response:

EMA raised the issue of reductant availability and infrastructure for both locomotives and marine vessels. As we explain in 4.3.1.1 of the RIA, we believe that there is adequate supply to satisfy the needs of the locomotive and marine sectors, and that there is adequate time to develop the supply/delivery infrastructure prior to implementation of the Tier 4 standards. We also believe that the centralized fueling nature of U.S.-based locomotive and marine operations will lend itself well to the migration and adaptation of urea supply solutions developed for the on-highway and nonroad sectors. For migratory vessels, which may operate in regions of the world where ULSD and/or reductant may not be available, a narrow exemption from the Tier 4 NOx standard is available (see section 3.2.5 of this Summary and Analysis of Comments document for a discussion of comments on vessels operating extensively outside the U.S.).

Concerning the commenters issue regarding urea freezing in Northern climates, as with our on-highway programs, we expect manufacturers will provide a method for thawing some portion of the frozen urea-water solution within a reasonable timeframe following a cold start. EPA's Urea Guidance Document for light-duty and heavy-duty vehicles states the following concerning urea freezing:

> "The reducing agent should not be adversely affected by extreme climatic conditions, particularly freezing temperatures. Some reducing agents freeze at temperatures that occur seasonally in certain parts of the U.S. Urea, for example, freezes at 11°F. Manufacturers need to either use a reducing agent that will not freeze at low temperatures, or design their SCR system to prevent freezing (e.g., use of heater elements in or around the storage tank and heated lines). Manufacturers who use a heated SCR system need to ensure that minimal "thaw" time is required to melt enough reducing agent to recharge the system, should the reducing agent freeze due to extensive exposure to low temperatures."

We believe many methods will develop for ensuring that the urea-water solution does not freeze during cold climate operation. These methods may range from insulated tanks/lines, electric- or coolant-heated tanks/lines, or a combination of both. Since line-haul locomotives do not use anti-freeze, any measures taken to prevent freezing of the engine coolant should allow similar opportunities to prevent urea freezing. We believe existing urea delivery and storage systems already provide thaw times of less than 4 hours. Advances in urea-SCR technologies will likely result in shorter thaw times, and we do not believe it is necessary to set a "minimum" thaw time at this point.

We are not specifying the reductant storage capacity for marine vessels or locomotives. It is expected that the manufacturers will provide enough onboard urea storage capacity to allow for uninterrupted NOx control, given the duty cycle, refueling, and usage patterns expected of each application.

10.4.5 Fuel Sulfur Level and Oil Formulation Effects

What Commenters Said:

EMA commented that an extremely important issue relating to the application of DPFs to marine applications is the fact that a large number of marine engines may operate on high sulfur fuel for substantial periods of time. The commenter raised the concern that, since the technology assumed by EPA is predicated on the use of ULSD, the operation on fuels other than ULSD will seriously impact regeneration efficiency and PM filter life. Additionally, the commenter stated that a serious concern with DPFs is the issue of trap plugging. The commenter noted that if regeneration does not occur on a regular basis, particulate filters can accumulate soot and create excessive backpressure, which can substantially reduce the power that the engine can generate. The commenter urged that an absolutely reliable regeneration capability must be available for filters that have the potential for plugging in marine applications. Lastly, the commenter stated that NOx aftertreatment technologies that do not use a separate reducing agent (non-additive) are not feasible for marine applications; the commenter stated that this is due to the fact that the demonstrated durability of the non-additive NOx aftertreatment approaches are not anywhere near what is needed for the marine environment.

Caterpillar and EMA commented that they believe EPA has underestimated the challenges for developing durable particulate aftertreatment systems. The commenters stated that EPA correctly states that phosphorous from the engine oil and sulfur from diesel fuel can deactivate a catalytic site, and cited EPA's statement (at 72 FR 15982) that "[t]he risk of catalyst deterioration due to sulfur poisoning will be all but eliminated with the 2012 implementation of ULSD fuel...." The commenters stated that this may be true for vessels always operating in the U.S. on ULSD, but is incorrect for U.S. vessels that will operate on high sulfur fuel when operating outside of the U.S. The commenters noted that many commercial vessels utilize ports outside the U.S., often for months at a time, and these ports will most likely have non-ULSD fuel which can deactivate catalysts. Caterpillar and EMA commented that the high fuel sulfur outside the U.S. will require the use of lubricating oil with higher (currently normal) ash to provide sufficient TBN to neutralize the sulfur making its way to the lubricating oil. The commenters stated that they are concerned that this higher ash will not be burned out of particulate filters and can increase the back pressure much more rapidly than would be seen with lubricants for ULSD; the ash accumulation will require more frequent cleaning of the particulate filters. EMA additionally commented that the extreme sensitivity to fuel sulfur makes non-additive NOx aftertreatment systems completely impractical due to the near certainty of exposure to fuel with significant sulfur levels in many marine applications.

EMA also commented that any final Tier 4 rule must ensure that adequate supplies of ULSD will be readily available at the U.S. ports that service and provide dockage to the commercial marine vessels and the very large recreational vessels that will be equipped with Tier 4 engines. Additionally, the commenter noted that the proposed Tier 4 PM standard will require the utilization of DPFs, which in turn require the consistent supply and utilization of ULSD to maintain emissions performance and to protect against potential overloading and clogging of the DPF system. The commenter further noted it is anticipated that the proposed Tier 4 NOx standard will require the utilization of SCR-based systems, which require the supply and use of aqueous urea as a reductant injected in the exhaust stream. The commenter requested that any vessel required to be equipped with Tier 4 engines and emission control systems must have ready and consistent access to adequate supplies of 15 ppm (or better) sulfur fuel and aqueous urea, and that the NPRM does not provide adequate assurance of this.

EMD commented that ULSD is an enabling technology for aftertreatment application and sulfur in diesel fuel has many deleterious effects on aftertreatment devices (such as: sulfate formation and catalyst poisoning in particulate traps, sulfate formation at high temperatures in oxidation catalysts, ammonium sulfate formation and catalyst fouling in selective catalytic reduction devices, and catalyst passivation in NOx adsorbers); therefore, a reliable supply of ULSD must be assured before aftertreatment can be introduced on the railroads, even for field test. The commenter noted that June 1, 2012 is the date for the refinery gate sulfur limit for locomotive and marine (LM) diesel fuel of 15 ppm. The commenter suggested that the start of the two-year field test of sulfur-sensitive aftertreatment must wait until the widespread availability of ULSD; otherwise, the test will fail due to misfueling with higher sulfur fuel and the objective of demonstrating system reliability will be lost. The commenter requested that, because of the need for a field test of at least two years and the need for time to evaluate the test results (including inspection of removed components), the earliest feasible date for introduction of aftertreatment on locomotives is January 1, 2015, as proposed in the NPRM. The commenter urged EPA to resist requests to accelerate aftertreatment application to earlier dates.

EMD further commented that the diesel fuel sulfur regulations (40 CFR Part 80, Subpart I) allow fuel with sulfur up to 500 ppm (such as transmix produced from fuel interfaces during pipeline shipment) to continue to be sold into the rail market indefinitely after June 1, 2012. The commenter stated that it believes that this poses a hazard for aftertreatment systems. The commenter stated that while the proposed locomotive rule requires units requiring ULSD to be so labeled near the fuel filler, such things are notoriously difficult to control on the railroads, and it will be difficult to ensure that aftertreatment-equipped locomotives receive only ULSD in service.

The New York State Department of Environmental Conservation commented that under current diesel fuel sulfur regulations, the ULSD necessary to support NOx and PM aftertreatment for locomotives will be available to railroads no later than fall 2012, and is available for research and development work today. The commenter further stated that the aftertreatment technologies expected to be employed, SCR and particulate traps, are well developed and currently in use in other applications. The commenter stated that it believes that aftertreatment based Tier 4 NOx and PM standards should be feasible with the availability of ULSD and should be implemented in 2013.

The Lake Carriers Association (LCA) commented that it believes that vessel operators must be assured that ULSD will be widely available in the U.S. marine market. The commenter further requested that the entity delivering the fuel to the vessel must provide assurance, perhaps through pump labeling, that the fuel being delivered is ULSD. The commenter also stated that a constant supply of urea is a necessity. The commenter stated that it believes that EPA should not mandate that engine performance be reduced (i.e., power derates) when urea is not available to the exhaust aftertreatment system.

EMD commented that, while it believes that it is too early to have full knowledge of the technology that will be required to meet the Tier 4 locomotive and marine engine emissions standards, it is concerned about the effects of oil ash deposition on catalyst durability; and the commenter stated that it believes EPA's view of the future of lubricating oil technology for these engines is overly optimistic and over simplified. The commenter cited EPA's statement that, "The high ash content in current locomotive and marine engine oil is related to the need for a high total base number (TBN) in the oil formulation. Because today's diesel fuel has relatively high sulfur levels, a high TBN in the engine oil is necessary today to neutralize the acids created when fuel-borne sulfur migrates to the crankcase. With the use of ULSD fuel, acid formation in the crankcase will not be a significant concern." The commenter stated that it believes that EPA's view is an over-simplification of a more complex issue. The commenter noted that technical requirements of engine oil require additional functionality in various areas which can increase the ash content of engine oil. EMD noted that EPA has indicated that locomotive and marine engine designs will have to reduce oil consumption to meet the Tier 3 and Tier 4 PM standards. The commenter raised the concern that the impact of those design changes will be to increase the stress on the engine oil, resulting in the need for an increase in detergency, metal deactivation, and dispersancy levels—which may increase the ash content of the oil and offset the effect of ULSD use. The commenter stated that it believes that without needed improvements in these areas, locomotive and marine engine owners will experience reduced oil life, with associated higher maintenance costs, and the potential for increased engine wear.

EMD commented that it is not necessarily true that the introduction of ULSD will make a simultaneous reduction on oil TBN requirements, especially because of the need to maintain alkaline reserve in the face of reduced oil consumption (which reduces the amount of fresh oil added to "sweeten the pot" or replenish the additive package) and the formation of organic acids (which also need to be neutralized if they enter the oil) during combustion. The commenter further stated that it believes that EPA's confidence in a future decline in rail and Category 2 marine engine oil TBN may be misplaced. The commenter raised the concern that only one oil formulation is used by the railroads, thus the various four-stroke (which tend to be harder on the oil because the blow-by gases go into the oil pan, rather than into the intake manifold as on a two-stroke) and two-stroke engines on a locomotive or marine vessel must utilize this same oil. The oil therefore must be designed for four-stroke operation; the commenter noted that the higher additization of oils developed for four-stroke operation, coupled with the higher oil consumption of two-strokes, means that more of the oil ash winds up in the exhaust on a two-stroke.

EMD also commented that the reference to on-highway low sulfated ash, phosphorous, and sulfur (low-SAPS) oil availability in October 2006 has no impact on the locomotive and marine diesel engine market. The commenter stated that highway engine oils are not designed to be used in current medium speed locomotive and marine diesel engines. The commenter noted that the additive chemistries are completely different and will require technological development by the additive and oil companies that serve the locomotive and marine markets as Tier 3 and Tier 4 engines are developed.

Letters:

Caterpillar	OAR-2003-0190-0594.1
Electro-Motive Diesel, Inc. (EMD)	OAR-2003-0190-0594.1
Engine Manufacturers Association (EMA)	OAR-2003-0190-0545, 0575.1
Lake Carriers' Association (LCA)	OAR-2003-0190-0567.1
New York State Department of Environmental Conservation	OAR-2003-0190-0583.1

Our Response:

Several commenters expressed their concern that ULSD – upon which the Tier 4 standards are based – will not be widely available when the standards take effect. The availability of ULSD is addressed in section 11.3.2 of this Summary and Analysis of Comments document. The fuel production and distribution industry is required to migrate to locomotive and marine (LM) ULSD in 2012, so the appropriate fuel should be available for Tier 4 engines. Even though low sulfur diesel fuel (LSD, fuel above 15 and at or below 500 ppm sulfur) may be available in the U.S. locomotive and marine market at that time, engines designed and certified by the manufacturer to operate only on ULSD must use this fuel at all times. Failure to do so will be considered tampering.

Also of concern with the availability of ULSD is the potential for clogging/plugging of the DPF (and the resultant increase in backpressure and loss of power) and de-activation of catalytic sites if higher sulfur fuel is used. Again, we believe that this issue only presents itself if the vessel is misfueled – where a "ULSD" label is either ignored or overlooked. For incidents of accidental misfueling, we do not believe that one tank of fuel with off-spec sulfur levels will permanently damage the exhaust aftertreatment devices. We expect that manufacturers, vessel owners, and fuel suppliers will implement the practices and methods used in the on-highway and nonroad sectors to deal with misfueling issues and ensure appropriate safeguards.

Oil formulation, and its importance to catalyst deterioration and engine life, were additional issues raised by several commenters. As the sulfur level in fuel is reduced, we expect that oil formulations will begin to change as well. In the 2007 heavy-duty highway truck market, with the introduction of DPFs and the switch-over to ULSD nationwide, the oil formulation was changed to a low-SAPS specification in order to accommodate the new operating conditions. While low-SAPS engine oil formulations may migrate to future locomotive and marine applications – which would be beneficial and directionally helpful in regards to the durability, performance, and maintenance of the exhaust aftertreatment components we reference – it is not a required element of our feasibility analysis. European truck and marine applications have shown that SCR is a durable technology, regardless of fuel sulfur level or oil ash content. One commenter suggested that these newer, low-SAPS oil formulations, developed for use in on-highway and nonroad diesel engines, may not be appropriate for locomotive or marine applications. While we acknowledge that the exact oil formulation for locomotive and marine applications using ULSD fuel is not known today, we do believe that there is adequate time to develop an appropriate oil formulation and DPF maintenance and ash cleaning intervals (if needed). For example, in the State of California, all intra-state locomotives, marine vessels (in the South Coast Air Quality Management District), and nonroad engines have been operating with ULSD since June 2006 – so there should already be field data/experience available today to begin understanding the effect that ULSD has on oil properties. In addition, the fuel production and distribution industry will be transitioning to 15 ppm nonroad (NR) nationwide in 2010, followed by 15 ppm LM in 2012 - again, leaving ample time to develop an oil formulation and additive package which meets the performance requirements of the locomotive and marine sectors. For marine vessels that spend much of their lives outside U.S. waters (in particular, places where ULSD is not available), there is a very narrow provision in the regulations to allow them to meet the Tier 3 emission standards instead of the aftertreatment-forcing Tier 4 emission standards (see Chapter 3 of this Summary and Analysis of Comments document for more detail on this subject).

10.4.6 Minimum Temperature for NOx Control

What Commenters Said:

EMA commented that, with respect to the technical feasibility of the Tier 4 NOx standards, EPA asserts that SCR NOx control strategies will "certainly be capable of precisely controlling NOx under all conditions whenever the exhaust temperature is greater than 150 °C." The commenter stated that this is inconsistent with the statement that urea hydrolyzes to CO and ammonia at higher temperatures (above 200 °C) (72 FR 15981). EMA commented that it believes that a minimum temperature of 250 °C must be included in the final rule, as this has been specified for nonroad and heavy-duty on-highway (HDOH) SCR systems. The commenter noted that exposure to higher sulfur fuels requires an even higher exhaust gas temperature for proper SCR operation. The commenter similarly stated that it believes that this minimum 250 °C temperature should also be used instead of the proposal to apply the NTE requirements for SCR-equipped engines when exhaust temperatures are at or above 150 °C (§1042.101(c)(2)(iv)(A)). EMA also commented that it believes that the NOx conversion efficiency under low temperature exhaust gas conditions can be improved by the use of an oxidation catalyst upstream of the SCR to promote the conversion of NO to NO_2. The commenter noted however that the few SCR systems currently in use on marine engines have generally not included an oxidation catalyst upstream, and thus such systems have not been adequately demonstrated in marine applications. (Additionally, the commenter noted that the SCR systems used in marine applications must be able to withstand prolonged periods of operation with fuel sulfur of greater than 0.5%.)

Letters:

Engine Manufacturers Association (EMA)	OAR-2003-0190-0575.1, 0545

Our Response:

We have reviewed our existing regulatory programs for on-highway and nonroad engines and agree that the NTE temperature threshold should be consistent between these programs. Therefore we are finalizing provisions consistent with our on-highway and nonroad standards (250 °C – see 40 CFR 86.1370-2007). While we believe that improvements in urea dosing technology may enable urea hydrolysis at temperatures as low as 150 °C, the current practice for urea-SCR systems is to stop urea injection whenever exhaust temperatures drop below 250 °C in order to ensure adequate urea hydrolysis and appropriate system function. However, while manufacturers are not constrained by the limits of the NTE requirements below the 250°C threshold, they can not modulate urea dosing in a way that reduces NOx control unless such an auxiliary emission control device (AECD) function was necessary to prevent engine damage or to ensure safe operation (e.g., to limit ammonia slip).

10.4.7 Exposure to Environmental Contaminants/Abrasives

What Commenters Said:

NJDEP responded to EPA's request for comment concerning a manufacturer's claim that locomotive catalyst systems must withstand sand exposure at a rate of 50 pounds/hr and 500 pounds/hr of red china clay and silicon flour at notch 8 (full power/speed). EPA asked whether sand exposure is an appropriate metric (given locomotive air-intake filtration and the ability of turbocharger systems to withstand such exposure). EPA also asked if these conditions were used for testing turbocharger systems and emissions compliance following such rates of engine ingestion of abrasive material. NJDEP commented that it cannot be imagined that locomotives do not employ intake air filters (99.95% efficient) and associated coarse particle pre-filter technology to prevent large quantities of abrasive particles to be drawn into the engines when operating in dusty environments. The commenter stated that, in all the experience of DOC, DPF, SCR, and DPF + SCR, no deterioration of catalyst function due to engine sand or dust ingestion has been noted. Information on turbo-charger testing regarding such exposure can be obtained from turbocharger manufacturers. With regard to question 1 from the NPRM, NJDEP commented that SCR systems are thermally resistant to extreme temperatures of 700 °C and above. The commenter stated that SCR would not be exposed to excessive soot since the proven DPF removes 99+% of all solid particles (the commenter noted that partial filters remove a lower percentage of solid particles, and therefore are of concern). The commenter also stated that DPF and SCR mounting systems isolate the ceramic catalysts from vibration and shock (but noted that attention must be paid to ensure the system is properly designed). The commenter noted that internal water exposure is ever present in exhaust systems and this internal source has not been found to cause any physical or functional damage; however, it is necessary to protect the catalyst from direct rain inundation. NJDEP noted that one DPF + SCR supplier did caution that trapped water could damage substrates upon rapid heat up. The commenter also noted that decline in performance due to salt exposure has not been noticed in either marine or ocean environments; and further, sand and dusts will be removed in the inlet air filter (99.95%). The commenter stated that no effect due to sand or dusts on DPF, SCR, or DPF +SCR system physical properties or performance has been encountered thus far. NJDEP noted that that engine-out soot will be cleansed with a BAT DPF system and therefore soot will not affect SCR catalysts. The commenter also stated that so-called partial filters would not prevent SCR soot and metal-ash exposure. Further, the commenter recommended that only verified best available filter technology be permitted. The commenter also stated that there is a need for a thorough SCR NOx verification procedure (there has already been one started in Europe, with an open invitation to EPA to join).

With regard to the NPRM's request for comment regarding catalyst exposure to salt fogs, NJDEP commented that there have been over 300 SCR units installed in marine environments in the Netherlands and a fair number are installed on ferries and ocean-going ships. The commenter stated that there have been no reported function or performance issues related to salt exposure for SCR catalysts over many years with individual in-use of many units over 10,000 hours in actual use.

Regarding the request for comment with respect to whether or not any catalyst packaging and/or installation issues would necessitate any direct exposure of catalyst substrates to weather, NJDEP commented that DPFs and SCR units are large in size and do present packaging and location issues. The commenter noted that this will be minimized if the DPF + SCR functions can be combined into one catalyst unit; the commenter also noted that non-cylindrical configurations help minimize the issue. The commenter stated that exposure to weather of fully enclosed assemblies avoids direct exposure of catalyst substrates and therefore is not a problem. The commenter noted that one manufacturer did express concern for water inundation of the SCR unit; to this end, the commenter stated that location in the space occupied by the acoustic muffler (only BAT DPF technology has muffling capability) is the ideal space but will require cooperative engineering work of engine makers and DPF + SCR system suppliers.

In its comments, GE provided detailed usage data to the question posed in the NPRM regarding how attributes of the locomotive operating environment could impact the ability of a Zeolite SCR-type catalyst to operate within 10% of its 'as new' conversion efficiency (~94%) after 34,000 MW-hours of operation:

- Water exposure due to rains, icing, water spray and condensed frozen or liquid water during 20% of its life.
- Salt fog consisting of 5+/-1% salt concentration by weight with fallout rate between 0.00625 and 0.0375 ml/cm2/hr.
- The catalysts will be subject to sands composed of 95% of SiO_2 with particle size between 1 to 650 microns in diameter with sand concentration of 1.1 +/-0.25 g/m3 and air velocity of 29 m/s (104 km/h).
- Exposure to dusts comprised of red china clay and silicon flour of particle sizes that are between 1 to 650 microns in diameter with dust concentration of 10.6 +/-7 g/m3 with a velocity equal to locomotive motion velocity on catalyst surfaces.

Caterpillar and EMA commented that engines operating on the ocean ingest salt from the general salt water spray, which will accumulate in the particulate filters and will not be oxidized. The commenters noted that the extent of this accumulation has not been assessed, but they noted that the impact may be the requirement of more frequent cleaning of non-combustible material or much shorter filter life requiring complete replacement of the filter. Caterpillar commented that filter plugging may occur so rapidly as to make their applications completely impractical. EMA further commented that it is also unknown exactly how salt spray ingestion might affect the SCR catalyst; poisoning and degradation of the catalyst are a real possibility.

EMA also noted that locomotive engines often operate in very dusty environments; the air filters remove most of the dust, but a small percentage gets through and this dust will not be removed during regeneration. The commenter noted that this will add to the ash build-up from the fuel and oil. The commenter further stated that the net effect of this will be more required maintenance for cleaning, and, if the cleaning methods do not completely restore the backpressure, a requirement to completely replace the particulate filters. EMA noted that nonroad Tier 4 applications beginning in 2011 have yet to be demonstrated in similar dusty applications.

MECA commented that locomotives and marine diesel engines will include air filtering elements designed to protect the engine and these same air filter elements will provide protection to the catalysts equipped on these engines from large particulates that might be present in the inlet combustion air to the engine. MECA also stated that it understands that some of the concerns raised for exposure to salt fog, sand, china clay, and silicon flour are military specifications for external surfaces of vehicles and are not pertinent to catalysts contained within the exhaust stream of a locomotive.

<u>Letters:</u>

Caterpillar	OAR-2003-0190-0485, 0594.1
Engine Manufacturers Association (EMA)	OAR-2003-0190-0545, 0575.1
General Electric Transportation (GE)	OAR-2003-0190-0590.1
Manufacturers of Emission Controls Association (MECA)	OAR-2003-0190-572.1
New Jersey Department of Environmental Protection (NJDEP)	OAR-2003-0190-0562.2

Our Response:

Several commenters raised concerns about the effect that environmental factors such as exposure to dust, abrasives, rain, and salt fogs will have on the performance and durability of aftertreatment components. In particular, EMA stated that for a wall-flow DPF, any dust which passes through the engine could be captured in the DPF, where it would become part of the incombustible “ash” mass. For locomotives in this environment – as it would be for marine, nonroad, or on-highway engines in a similar environment – the frequency of the ash cleaning maintenance would increase unless measures are taken to reduce the amount of dust and contaminants entering the engine. We believe that this scenario (where contaminants pass through the engine and are trapped by the DPF) is best dealt with by filtering air before it enters the engine. The commenter does not state a level of contaminant ingestion that today's engines experience when operated in the conditions described (nor what affect such levels would have on engine durability, let alone durability of the aftertreatment components.) We believe that solutions already exist in the construction vehicle sector to deal with air filtration in dusty environments.

Several commenters also raised concerns about exposure of catalyst components to rain, ice, and salt fogs. We expect that locomotive manufacturers and vessel builders will install the appropriate shields, baffles, and/or water drainage paths to protect the catalyst components from direct exposure to these environmental hazards. For salt fog exposure, articulated flaps, caps, or doors can be employed to close the exhaust stack when the engine is not running.

10.4.8 Vibration and Shock Loads

What Commenters Said:

AAR commented that an important operating factor is vibration, exacerbated by the location of aftertreatment devices above the engine. The commenter stated that whether catalysts can maintain their efficiency at such high temperatures and extended periods of significant vibration is at best unknown.

NJDEP provided comments in response to EPA's request for comments on various issues. The commenter noted that EPA requested more specific information regarding shock and vibration, soot exposure, and temperature exposure for existing zeolite-based SCR or under development; NJDEP hired Dr. John Mooney to address these topics. Regarding shock and vibration, NJDEP noted that mounting technologies for ceramic catalysts are well developed, broadly applied, and already proven for locomotive applications. The commenter noted that shock and vibration effects, if noticed in applications, are corrected utilizing established catalyst mounting technology. The commenter further stated that it is noted that RFQ specifications to technology suppliers for new Tier 4 engines will most certainly include reasonable and appropriate engineering-based shock and vibration test and limits for DPF + SCR systems.

GE noted that the NPRM indicated that thermal and mechanical vibration durability of catalysts is an issue and that the NPRM stated that it has been addressed through the selection of proper materials and the design of support and mounting structures capable of withstanding the shock and vibration levels present in locomotive and marine applications. However, the commenter stated that it does not believe that this statement is supported in the record. The commenter stated that the expected shock loading of the catalyst is estimated at 10G-12G, based on a 2G force shock loading at the coupling (with a typical locomotive experiencing 1000 such pulses each year) being transmitted to the catalyst. The catalyst is also subject to periods of vibration, where the load can reach 6G at a frequency of 1000 Hertz (Hz). GE also commented that, to its knowledge, no source of information supports the proposition that the catalyst can withstand this shock. The commenter further stated that, given the fact that trucks do not have to withstand this shock loading, EPA must at least evaluate the ability of the catalyst to withstand the shock loading before promulgating the standard and must respond substantively to these concerns. GE commented that if the catalyst cannot withstand these loadings, EPA should adjust the standard (or require catalyst manufacturers to warrant based on the shock loadings expected).

MECA commented that Zeolite-based SCR catalysts are expected to withstand the mechanical and ambient conditions required for locomotive applications. The commenter noted that SCR systems have already been designed, or are being designed, to deal with mechanical and thermo-mechanical conditions associated with passenger cars, trucks, and marine vessels. The commenter stated that it believes that these mechanical and ambient conditions are expected to be no more severe for locomotive applications. The commenter also noted that durability under thermo-mechanical environments depends on both the physical strength of the catalyst element and the design of the packaging system that contains the catalyst element(s). MECA commented that its members have considerable experience in packaging catalysts for severe thermo-mechanical environments. The commenter noted that system design engineers can utilize a variety of tools, including hot vibration testing and engine testing, to design and validate effective system designs that can withstand the thermo-mechanical environment present in the exhaust.

Letters:

Association of American Railroads (AAR)	OAR-2003-0190-0566.1
General Electric Transportation (GE)	OAR-2003-0190-0590.1
Manufacturers of Emission Controls Association (MECA)	OAR-2003-0190-572.1
New Jersey Department of Environmental Protection (NJDEP)	OAR-2003-0190-0562.2

Our Response:

GE's estimation of a "10G-12G level of shock loading" is consistent with EPA's understanding of what catalyst substrate manufacturers, catalyst canners, and exhaust system manufacturers are currently designing for components subject to the durability requirements for on-highway, marine, and nonroad Tier 4 applications. In nonroad applications such as logging equipment, the exhaust system components can be subject to shock loads as high as 20 G, and catalysts tested in these applications have not had significant problems with durability when subjected to shock loads at this level. Furthermore, we reference the ABS specification for exhaust manifolds on diesel engines, which states that loads can be as high as +/-10 G at 600 °C. Based on the experience that manufacturers have with catalysts on existing equipment and vehicles, we do not believe that vibration and shock loading will prevent their use on locomotive and marine applications.

10.4.9 Aftertreatment Maintenance/Replacement Intervals

What Commenters Said:

GE commented that analysis of recent data shows that elements of the catalyst system (i.e., the DOC) will need to be replaced at intervals somewhere between 4 months and 2 years, at a cost to the railroads on the order of $60,000 per replacement. The commenter stated that each such replacement will require the locomotive to be removed from service and moved to a facility equipped with the appropriate cranes and other equipment to replace the catalyst. The commenter raised the concern that neither the cost nor the extreme disruptions of removing locomotives from service were taken into account in the proposal; the commenter stated that EPA appears to assume that the catalyst will not need to be replaced at any intervals. GE also commented that there are 2006 and 2007 studies that have been conducted using ULSD and low sulfur oil on real (rather than simulated) diesel exhaust using zeolite catalysts. The commenter noted that these studies show that use of ULSD as a fuel and low sulfur oil is not sufficient to prevent poisoning of the catalyst, thus reducing the conversion efficiency; the commenter stated that it has analyzed the data presented in these papers to determine the replacement intervals required to assure compliance with a 1.3 g/bhp-hr NOx standard over the useful life of the locomotive.

Letters:
General Electric Transportation (GE)OAR-2003-0190-0590.1

Our Response:

Regarding the commenter's concern about catalyst system durability and their expectation of a short service interval, we refer to Chapter 4 of the Final RIA, where a detailed analysis of catalyst durability is presented. In particular, Figures 30 and 31 offer evidence that catalyst performance does not deteriorate appreciably under the conditions present in locomotive operation (which are similar to those in marine operations) – even when exposed to accelerated oil and ash poisoning and high hours simulating the full useful life of the engine.

10.4.10Requests for Technology Reviews and Feasibility Analysis

What Commenters Said:

In its comments, GE provided suggested regulatory language modeled on prior EPA rules regarding a catalyst technology review and petition process. The commenter stated that, unlike the review EPA conducted in 1999 for the 1997 heavy-duty truck standards, the language that it provided is narrowly crafted to minimize the burden on EPA and provide certainty as stakeholders invest in achieving the Tier 4 standards. GE noted, for example, that it is not requesting a wholesale technology review or for EPA to revisit the space constraint issues; it instead seeks only a targeted catalyst deterioration evaluation that can be conducted after further research and development have been conducted. The commenter stated that it believes that 2010 is the appropriate time for the formal review to occur because it allows for progress in catalyst technology while still being consistent with a development timeframe. The commenter suggested that the review be performed no later than December 31, 2010, and that EPA revise the standard if the catalyst deterioration is greater than EPA has estimated in establishing the Tier 4 standard. The commenter also requested that EPA state in the final rule what deterioration rate is being assumed for the catalyst in arriving at the final Tier 4 NOx standard. The commenter suggested that EPA could model the language on the provision it used for the heavy duty engine technology review, as promulgated in 1997.

GE also commented that EPA should recognize that over the next 10 years, additional technology advancements may occur that would reduce emission levels, and the rules should allow manufacturers to take these technologies into account in determining the certified emission level. The commenter also noted that there could be many viable NOx-reducing technologies, and the commenter believes that the final rule should not restrict the methods by which manufacturers might meet the Tier 4 NOx (or any other) standard. The commenter further urged that EPA ensure that the regulatory language does not act as a barrier to implementation of such technologies that achieve emission reductions, particularly where they can rely on pollution prevention rather than add-on controls.

EMD commented that there is time for development work on the technology that EPA proposes to apply to locomotives in the 2015 to 2017 timeframe and to marine vessels starting in 2014. EMD commented that, under these circumstances, it is willing to proceed without challenging the standards that would force the introduction of such technology to locomotives and marine engines. However, the commenter requested that EPA include provisions in the final rule for periodic technical reviews of progress toward meeting the standards, and whether the standards continue to be appropriate under paragraph 213(a)(5) of the Clean Air Act. The commenter suggested that these reviews should begin no later than the year 2010, as a 2015 application of componentry representing such a major departure from current locomotive and marine engine practice will require a multiple-unit field test beginning at least by 2012, and design work should get under way at least by 2010. EMD suggested that the reviews should continue at least annually thereafter. The commenter further suggested that, because of the competitive situation between major locomotive and engine manufacturers, EPA should conduct the reviews with each manufacturer separately. Lastly, EMD commented that it believes that the worst possibility that could come out of this rulemaking would be to shut down major suppliers to the rail and marine transportation industries because the last bit of emissions reduction proved unattainable.

EMA noted that the preamble (72 FR 15980) identified four main issues relating to aftertreatment systems; 1) the efficacy of the fundamental catalyst technology in terms of the percent reduction in emissions given certain engine conditions such as exhaust temperature, 2) applicability in terms of packaging, 3) long-term durability, and 4) whether or not the technology significantly affects an industry’s supply chain infrastructure - especially to supplying urea reductant for SCR to locomotives and vessels. EMA commented that it believes there are many more issues that must be addressed in assessing the application of DPF aftertreatment systems to marine applications. The commenter stated that the other significant questions that must be resolved by EPA in finalizing the rule include the following:

1) Can passive regeneration be relied on to ensure oxidation of trapped soot under all operating conditions? (The commenter noted that most observers believe that the answer to this is “no,” and this is especially true for engines where the engine-out NOx level is controlled to a low level.)
2) Can potential increases in NO_2 emissions be minimized and maintained at acceptable levels?
3) Can effective active regenerating schemes be developed to ensure that trapped soot can be oxidized effectively under all engine operating conditions?
4) Will active regenerating systems be reliable and dependable over the full useful life of the engine?
5) Can increases in emission constituents (primarily HC) be avoided during regeneration events?
6) Can safety issues associated with extremely hot exhaust gas and exhaust system components during regeneration events be successfully addressed?
7) Can maintenance burdens associated with filter ash removal be reduced to an acceptable level?
8) Can DPF systems be designed and packaged such that they can be accommodated within the applicable space constraints without exceeding exhaust back-pressure limits?
9) Can CDPFs be made functionally and physically compatible with the NOx aftertreatment systems that will also be required?
10) Can the costs of these systems (including acquisition costs, maintenance costs and operating costs) be reduced to an acceptable level?
11) Will CDPFs be accepted in the marine marketplace?

Letters:
Electro-Motive Diesel, Inc. (EMD) OAR-2003-0190-0594.1
Engine Manufacturers Association (EMA) OAR-2003-0190-0545, 0575.1
General Electric Transportation (GE) OAR-2003-0190-0590.1

Our Response:

Several commenters asked that EPA commit to a future technology review (or series of reviews) to assess the progress of Tier 4 technology development for the locomotive and marine sectors (as has been done in the past for other EPA mobile source programs involving advanced technology), and, if appropriate, to revise the program standards or implementation schedule accordingly. Many of the questions posed by EMA have been addressed in Chapter 4 of the RIA and in this Summary & Analysis of Comments as follows:

EMA Question #	**Summary & Analysis of Comments Reference**
1,2	10.2.6, 10.2.7, 10.3.7
3	10.2.4
4	10.2.4 and 10.4.3
5	(*see below*)
6	10.3.7
7	10.2.7 and 10.2.8
8	10.2.8
9	10.2.1
10	10.1.2.3, 10.2.1 (and S&A chapter 5)
11	10.3.7

Concerning EMA question #5, the increases in HC emissions can be minimized through careful system design and calibration. In addition, we expect that regeneration events will be infrequent, and as such, any increase in emission constituents can be factored into the emissions certification test result.

As with all of our technology-forcing standards, we believe that the smooth implementation of this program calls for EPA's continued involvement in assessing and encouraging technology development. Should significant new information come forward that prompts a reconsideration of these standards we would, as a matter of course, pursue this. As discussed in detail in Chapter 4 of the Final RIA, we agree that much engineering work remains to be done to migrate advanced aftertreatment technologies into the locomotive and large marine diesel sectors. We believe, however, that the engineering and development path in the several years before the Tier 4 phase-in is clearly laid out, and that a commitment to a formal review is not warranted, and indeed could prove disruptive. We note that interest in a future technology review on a predetermined schedule was by no means universal among those in the affected industries who commented, recognizing that this creates some element of uncertainty for the long-term program.