

performance.¹⁶⁷ Additionally, exhaust temperatures well in excess of 500°C are not frequently experienced by nonroad engines. Higher exhaust temperatures would be expected from naturally aspirated engines due to their lower air flow (for the same power/heat input, naturally aspirated engines have less air to heat up and thus the exhaust reaches a higher temperature). Today, less than ten percent of nonroad diesel engines with rated power greater than 100 horsepower are naturally aspirated and we have projected that an even greater percentage of nonroad engines meeting the Tier 3 emission standards will be turbocharged.

We have conducted an analysis of various nonroad equipment operating cycles and various nonroad engine power density levels to better understand the matching of nonroad engine exhaust temperatures, catalyst installation locations and catalyst technologies. This analysis, documented in the draft RIA, showed that for many engine power density levels and equipment operating cycles, exhaust temperatures are quite well matched to catalyst temperature window characteristics. In particular, the nonroad transient cycle (NRTC), the cycle we are proposing to use for certification, was shown to be well matched to the NO_x adsorber characteristics with estimated performance in excess of 90 percent for a turbocharged diesel engine tested under a range of power density levels. The analysis also indicated that the exhaust temperatures experienced over the NRTC are better matched to the NO_x adsorber catalyst temperature window than the temperatures that would be expected over the highway FTP test cycle. This suggests that compliance with the proposed NRTC will be somewhat easier, using similar technology, than complying with the highway 2007 emission standards on the FTP.

For engines with low power density (e.g., <25 hp per liter of engine displacement) the analysis showed that, absent actions to increase exhaust temperatures (e.g., increased use of EGR at light loads), compliance with the NRTC cycle will be more difficult than for engines with higher power density levels. Specifically, the analysis predicted 92% control for the high power density engine and 86% control for the low power density engine.

Note that this analysis approach is only effective to predict differences in

performance, but not effective to predict absolute performance. The same analysis approach predicted 83% control for the high power density engine on the heavy-duty FTP, although testing at EPA has shown for this engine (a different example of this same engine) greater than 90% NO_x control.¹⁶⁸ Nevertheless, the analysis suggests that additional attention must be made to designing system for low power density applications, and that technology changes may be necessary to ensure adequate performance (e.g., the use of EGR or other control methods to raise exhaust temperatures). One change, which is occurring independent of EPA's regulation, is increasing power density for nonroad engines. EPA has documented in the draft RIA a clear trend of certified engine ratings that indicates manufacturers are increasing engine power without increasing engine displacement. Engine manufacturers are motivated to increase engine power density because engine pricing is largely done on a power basis, while the cost of manufacturing is more closely related to engine displacement. Therefore, increasing engine power levels without increasing displacement may increase the sale price of the engine more than it increases the cost of manufacturing. Increasing power density typically results in higher exhaust temperatures and, in this case, better matching to catalyst operating requirements. Alternatively, nonroad engine manufacturers can apply the same temperature management strategies previously described for highway engines.

The analysis also suggests that the temperature challenge for nonroad equipment will be greater with regard to the NTE provisions of this proposal than for the nonroad transient test (NRTC) provisions. In fact as discussed previously, the NRTC cycle appears to be a better match to the characteristics of the NO_x adsorber catalyst than the FTP cycle used for heavy-duty highway truck certification. This is due to the higher average engine load experienced over the NRTC and thus the higher average temperature. Therefore, we believe that complying with the NO_x standard over the transient test cycle proposed today for nonroad engines will not be significantly more difficult than complying with the HD2007 NO_x emission standard over the FTP. The analysis also shows that many nonroad engines may operate in-use in a way

different from the NRTC (*i.e.* even the NRTC is not an all-encompassing test; no single test realistically could be), and that NTE standards are therefore needed to assure that nonroad engine emissions are controlled for the full range of possible in-use operating conditions.¹⁶⁹ The technical challenge of controlling NO_x emissions, even under these diverse conditions, is no more difficult on a per engine basis than for highway diesel engines which must comply with similar NTE test provisions. This is because both highway and nonroad engine manufacturers must address control at the same high load and low load conditions (minimum power from both are the same, 0 hp, and maximum power is typically higher for highway engines, due to higher power density). Also, both engine manufacturers must be able to respond to changes in user demanded torque (transient conditions) that are similarly unpredictable. However, given the sheer number of different nonroad equipment types and engine ratings, this represents a real challenge for the nonroad industry which is one of the primary considerations given by the Agency in determining the appropriate timing for the emission standards proposed today.

We believe, based on our analysis of nonroad engines and equipment operating characteristics, that in-use some nonroad engines will experience conditions that require the use of temperature management strategies in order to effectively use the NO_x adsorber and CDPF systems needed to meet the proposed standards. We have assumed in our cost analysis that all nonroad engines complying with a PM standard of 0.02 g/bhp-hr or lower will have an active means to control temperature (*i.e.* we have costed a backup regeneration system, although some applications likely may not need one). We have made this assumption believing that manufacturers will not be able to accurately predict in-use conditions for every piece of equipment and will thus choose to provide the technologies on a back-up basis. As explained earlier, the technologies necessary to accomplish this temperature management are enhancements of the Tier 3 emission control technologies that will form the

¹⁶⁷ Damson, B., "Exhaust Cooling for NO_x-Traps for Lean Spark-Ignition Engines," SAE 2002-01-0737.

¹⁶⁸ Schenk, C., McDonald, J. and Olson, B. "High Efficiency NO_x and PM Exhaust Emission Control for Heavy-Duty On-Highway Diesel Engines," SAE 2001-01-1351.

¹⁶⁹ The fact that developing compliant engines for the NTE provisions may be more difficult than developing for the transient test cycle does not diminish the value of the transient test as a means to evaluate the overall effectiveness of the emission control system under transient conditions. There is no doubt that controlling average emissions under transient conditions will be an important part of the emission control system and that evaluating overall performance under transient conditions is needed.