

manufacturers and has been a focus of our ongoing diesel engine progress review. There we have learned that substantial progress is being made to broaden the operating temperature window of catalyst technologies while at the same time engine systems are being designed to better control exhaust temperatures. Highway diesel engine manufacturers are working to address this need through modifications to engine design, modifications to engine control strategies and modifications to exhaust system designs. Engine design changes, including the ability for multiple late fuel injections and the ability to control total air flow into the engine, give controls engineers additional flexibility to change exhaust temperature characteristics.

Modifications to the exhaust system, including the use of insulated exhaust manifolds and exhaust tubing, can help to preserve the temperature of the exhaust gases. New engine control strategies designed to take advantage of engine and exhaust system modifications can then be used to manage exhaust temperatures across a broad range of engine operation. The technology solutions being developed for highway engines to better manage exhaust temperature are built upon the same emission control technologies (*i.e.*, advanced air handling systems and electronic fuel injection systems) that we expect nonroad engine manufacturers to use in order to comply with the Tier 3 emission standards.

Matching the operating temperature window of the broad range of nonroad equipment may be somewhat more challenging for nonroad engines than for many highway diesel engines simply because of the diversity in equipment design and equipment use. Nonetheless, the problem has been successfully solved in highway applications facing low temperature performance situations as difficult to address as any encountered by nonroad applications. The most challenging temperature regime for highway engines are encountered at very light-loads as typified by congested urban driving. Under congested urban driving conditions exhaust temperatures may be too low for effective NO<sub>x</sub> reduction with a NO<sub>x</sub> adsorber catalyst. Similarly, exhaust temperatures may be too low to ensure passive CDPF regeneration. To address these concerns, light-duty diesel engine manufacturers have developed active temperature management strategies that provide effective emissions control even under these difficult light-load conditions. Toyota has shown with their prototype DPNR

vehicles that changes to EGR and fuel injection strategies can realize an increase in exhaust temperatures of more than 100°F under even very light-load conditions allowing the NO<sub>x</sub> adsorber catalyst to function under these normally cold exhaust conditions.<sup>165</sup> Similarly, PSA has demonstrated effective CDPF regeneration under demanding light-load taxi cab conditions with current production technologies.<sup>166</sup> Both of these are examples of technology paths available to nonroad engine manufacturers to increase temperatures under light-load conditions.

We are not aware of any nonroad equipment in-use operating cycles which would be more demanding of low temperature performance than passenger car urban driving. Both the Toyota and PSA systems are designed to function even with extended idle operation as would be typified by a taxi waiting to pick up a fare. By actively managing exhaust temperatures engine manufacturers can ensure highly effective catalyst based emission control performance (*i.e.*, compliance with the emission standards) and reliable filter regeneration (failsafe operation) across a wide range of engine operation as would be typified by the broad range of in-use nonroad duty cycles and the new nonroad transient test proposed today.

The systems described here from Toyota and PSA are examples of highly integrated engine and exhaust emission control systems based upon active engine management designed to facilitate catalyst function. Because these systems are based upon the same engine control technologies likely to be used to comply with the Tier 3 standards and because they allow great flexibility to trade-off engine control and catalyst control approaches depending on operating mode and need, we believe most nonroad engine manufacturers will use similar approaches to comply with the emission standards proposed today. However, there are other technologies available that are designed to be added to existing engines without the need for extensive integration and engine management strategies. One example of such a system is an active DPF system developed by Deutz for use on a wide

range on nonroad equipment. The Deutz system has been sold as an OEM retrofit technology that does not require changes to the base engine technology. The system is electronically controlled and uses supplemental in-exhaust fuel injection to raise exhaust temperatures periodically to regenerate the DPF. Deutz has sold over 2,000 of these units and reports that the systems have been reliable and effective. Some manufacturers may choose to use this approach for compliance with the PM standard proposed today, especially in the case of engines which may be able to comply with the proposed NO<sub>x</sub> standards with engine-out emission control technologies (*i.e.*, engines rated between 25 and 75 horsepower).

High temperature operating regimes such as a heavy heavy-duty diesel truck at full payload driving up a grade are also challenging for the NO<sub>x</sub> catalyst technology. Although less common, similar high temperature conditions of full engine load operation can be imagined for nonroad equipment. However, because highway engines typically have higher power density (defined as rated power divided by engine displacement), the highest operating conditions would be expected to be encountered with highway vehicles. High exhaust temperatures (in excess of 500°C) are challenging for the NO<sub>x</sub> adsorber catalyst technology because the stored NO<sub>x</sub> emissions can be released thermally without going through a reduction step, leading to increased NO<sub>x</sub> emissions. In the absence of a reductant (normally provided by the standard NO<sub>x</sub> regeneration function) the thermally released NO<sub>x</sub> is emitted from the exhaust system without treatment. To address this issue, NO<sub>x</sub> storage catalyst technologies with higher levels of thermal stability are being developed, but these technologies trade-off improved high temperature performance for even greater sensitivity to fuel sulfur. Beyond catalyst improvements, the exhaust temperature from the engine can be controlled prior to the NO<sub>x</sub> adsorber catalyst simply through heat loss in the exhaust system (*i.e.* by locating the catalyst further from the engine). Another approach being considered for GDI vehicle applications which operate at much higher temperatures than would be encountered by a diesel engine is to use a relatively simple exhaust layout design to increase heat loss at high temperatures while still providing acceptable low temperature

<sup>165</sup> Sasaki, S., Ito, T., and Iguchi, S., "Smoke-less Rich Combustion by Low Temperature Oxidation in Diesel Engines," 9th Aachener Kolloquium Fahrzeug—und Motorentechnik 2000. Copy available in EPA Air Docket A-2001-28.

<sup>166</sup> Jeuland, N., *et al.*, "Performances and Durability of DPF (Diesel Particulate Filter) Tested on a Fleet of Peugeot 607 Taxis First and Second Test Phases Results," October 2002, SAE 2002-01-2790.