

the period of time between desulfation events is expected to be determined by the amount of sulfur accumulated on the catalyst (the higher the sulfur accumulation rate, the shorter the period between desulfation events) the desulfation frequency is expected to be proportional to the fuel sulfur level. In other words for each doubling in the average fuel sulfur level, the frequency and accumulated number of desulfation events are expected to double. We concluded in the HD2007 rulemaking, that this thermal degradation would be unacceptable high for fuel sulfur levels greater than 15 ppm. Some commenters to the HD2007 rule suggested that the NO<sub>x</sub> adsorber technology could meet the HD2007 NO<sub>x</sub> standard using diesel fuel with a 30 ppm average sulfur level. This would imply that the NO<sub>x</sub> adsorber could tolerate as much as a four fold increase in desulfation frequency (when compared to an expected seven to 10 ppm average) without any increase in thermal degradation. That conclusion was inconsistent with our understanding of the technology at the time of the HD2007 rulemaking and remains inconsistent with our understanding of progress made by industry since that time. Diesel fuel sulfur levels must be at or below 15 ppm in order to limit the number and frequency of desulfation events. Limiting the number and frequency of desulfation events will limit thermal degradation and, thus, enable the NO<sub>x</sub> adsorber technology to meet the NO<sub>x</sub> standard.

This conclusion remains true for the highway NO<sub>x</sub> adsorber catalyst technology that this proposal is based upon and will be equally true for nonroad engines applying the NO<sub>x</sub> adsorber technology to comply with our proposed Tier 4 standards.

Nonroad and highway diesel engines are similarly durable and thus over their lifetimes consume a similar amount of diesel fuel. This means that both nonroad and highway diesel engines will have the same exposure to sulfur in diesel fuel and thus will require the same number of desulfation cycles over their lifetimes. This is true independent of the test cycle or in-use operation of the nonroad engine.

Sulfur in diesel fuel for NO<sub>x</sub> adsorber equipped engines will also have an adverse effect on fuel economy. The desulfation event requires controlled operation under hot and net fuel rich exhaust conditions. These conditions, which are not part of a normal diesel engine operating cycle, can be created through the addition of excess fuel to the exhaust. This addition of excess fuel causes an increase in fuel consumption.

Future improvements in the NO<sub>x</sub> adsorber technology, as we have observed in our ongoing diesel progress reviews, are expected and needed in order to meet the NO<sub>x</sub> emission standards proposed today. Some of these improvements are likely to include improvements in the means and ease of removing stored sulfur from the catalyst bed. However because the stored sulfate species are inherently more stable than the stored nitrate compounds (from stored NO<sub>x</sub> emissions) and so will always be stored preferentially to NO<sub>x</sub> on the adsorber storage sites, we expect that a separate release and reduction cycle (desulfation cycle) will always be needed in order to remove the stored sulfur. Therefore, we believe that fuel with a sulfur level at or below 15 ppm sulfur will be necessary in order to control thermal degradation of the NO<sub>x</sub> adsorber catalyst and to limit the fuel economy impact of sulfur in diesel fuel.

#### b. Sulfate Particulate Production and Sulfur Impacts on Effectiveness of NO<sub>x</sub> Control Technologies

The NO<sub>x</sub> adsorber technology relies on a platinum based oxidation function in order to ensure high NO<sub>x</sub> control efficiencies. As discussed more fully in section III.F.1, platinum based oxidation catalysts form sulfate PM from sulfur in the exhaust gases significantly increasing PM emissions when sulfur is present in the exhaust stream. The NO<sub>x</sub> adsorber technology relies on the oxidation function to convert NO to NO<sub>2</sub> over the catalyst bed. For the NO<sub>x</sub> adsorber this is a fundamental step prior to the storage of NO<sub>2</sub> in the catalyst bed as a nitrate. Without this oxidation function the catalyst will only trap that small portion of NO<sub>x</sub> emissions from a diesel engine which is NO<sub>2</sub>. This would reduce the NO<sub>x</sub> adsorber effectiveness for NO<sub>x</sub> reduction from in excess of 90 percent to something well below 20 percent. The NO<sub>x</sub> adsorber relies on platinum to provide this oxidation function due to the need for high NO oxidation rates under the relatively cool exhaust temperatures typical of diesel engines. Because of this fundamental need for a precious metal catalytic oxidation function, the NO<sub>x</sub> adsorber inherently forms sulfate PM when sulfur is present in diesel fuel, since sulfur in fuel invariably leads to sulfur in the exhaust stream.

The Compact-SCR technology, like the NO<sub>x</sub> adsorber technology, uses an oxidation catalyst to promote the oxidation of NO to NO<sub>2</sub> at the low temperatures typical of much of diesel engine operation. By converting a portion of the NO<sub>x</sub> emissions to NO<sub>2</sub>

upstream of the ammonia SCR reduction catalyst, the overall NO<sub>x</sub> reductions are improved significantly at low temperatures. Without this oxidation function, low temperature SCR NO<sub>x</sub> effectiveness is dramatically reduced making compliance with the NO<sub>x</sub> standard impossible. Therefore, future Compact-SCR systems would need to rely on a platinum oxidation catalyst in order to provide the required NO<sub>x</sub> emission control. This use of an oxidation catalyst in order to enable good NO<sub>x</sub> control means that Compact SCR systems will produce significant amounts of sulfate PM when operated on anything but the lowest fuel sulfur levels due to the oxidation of SO<sub>2</sub> to sulfate PM promoted by the oxidation catalyst.

Without the oxidation catalyst promoted conversion of NO to NO<sub>2</sub>, neither of these NO<sub>x</sub> control technologies can meet the proposed NO<sub>x</sub> standard. Therefore, each of these technologies will require low sulfur diesel fuel to control the sulfate PM emissions inherent in the use of highly active oxidation catalysts. The NO<sub>x</sub> adsorber technology may be able to limit its impact on sulfate PM emissions by releasing stored sulfur as SO<sub>2</sub> under rich operating conditions. The Compact-SCR technology, on the other hand, has no means to limit sulfate emissions other than through lower catalytic function or lowering sulfur in diesel fuel. The degree to which the NO<sub>x</sub> emission control technologies increase the production of sulfate PM through oxidation of SO<sub>2</sub> to SO<sub>3</sub> varies somewhat from technology to technology, but it is expected to be similar in magnitude and environmental impact to that for the PM control technologies discussed previously, since both the NO<sub>x</sub> and the PM control catalysts rely on precious metals to achieve the required NO to NO<sub>2</sub> oxidation reaction.

At fuel sulfur levels below 15 ppm this sulfate PM concern is greatly diminished. Without this low sulfur fuel, the NO<sub>x</sub> control technologies are expected to create PM emissions well in excess of the PM standard regardless of the engine-out PM levels. Thus, we believe that diesel fuel sulfur levels will need to be at or below 15 ppm in order to apply the NO<sub>x</sub> control technology.

#### G. Reassessment of Control Technology for Engines Less Than 75 hp in 2007

By structuring our program to benefit extensively from prior experience with core technologies in the highway sector, we believe that a nonroad diesel technology review of the extent being pursued for the heavy-duty highway