C. Exhaust After-Treatment and Engine Technologies

General comments on exhaust after-treatment and engine technologies:

a) One commenter stated that MSHA should reevaluate the remaining types of light-duty equipment currently operating underground to determine if additional equipment should be included under §72.501. For example, in the 2001 rule, MSHA required generators and compressors to meet the same DPM emission limits as heavy-duty equipment based on their contribution to miners' exposure to DPM. [Comment].

b) A second commenter stated that MSHA must take into account the crucial role of the original equipment manufacturers (OEM) in developing equipment suitable for use in the mine environment, and that Tier 4 engine technology has not yet fully matured. This commenter went on to say that, once enhanced engines and monitoring equipment become more readily available, mines will need adequate time to plan capital expenditures, evaluate equipment, and revise maintenance schedules and procurement contracts well in advance of any future compliance date. This commenter stated that it is vital for MSHA to consider these practical challenges working in partnership with stakeholders in the context of the inter-agency approach.

c) A third commenter stated that, in addition to producing lower emissions, Tier 4 engines require low sulfur fuel and low ash oil, which also improve air quality. This commenter stated that the increase in costs would be offset by improved motor performance.

d) A fourth commenter explained how diesel particulate filter (DPF) performance is enhanced by using biodiesel fuel - the use of biodiesel with DPF can promote regeneration in the DPF systems because of underground mines tendency to have a low balance point temperature. This can eliminate extra expenses related to DPFs and negate the need for active regeneration of the filters.

e) A fifth commenter described targeted improvements to reduce exposures for two high exposure groups, shotcreters and magazine keepers, and included a data table [Commenter (Figure 2, p. 5)]. Continuously Regenerating Trap (CTR) DPFs fitted on shotcrete rigs achieved a 99% reduction in emissions. To reduce exposures to the Magazine Keeper, vehicles were rerouted away from the magazine. For other [similar exposure groups] SEGs, any exposure measurement recorded in excess of 0.03 mg/m^3 is investigated to identify and address the reasons. This commenter noted that intrinsic safety is not a limiting factor in equipment implementation at MNM mines, and described controls under development at a MNM mine including:

- Using high quality, low sulfur diesel fuel
- Engaging with suppliers to improve engine design and exhaust treatment devices
- Replacing older diesel equipment with new technologies where possible
- Replacing open cabin machinery and vehicles with enclosed cabin equipment fitted with air filtration units
- Installation of diesel exhaust filtration devices to heavy underground machinery e.g. jumbos and trucks
- Increased ventilation in mine areas where diesel equipment is in use
- Focused attention on high exposure SEGs.

f) One commenter submitted two spreadsheets containing diesel equipment inventories for 13 coal mines. [Equipment Inventory1], [Equipment Inventory2].

g) Four commenters submitted a total of five reports or published studies evaluating effectiveness of after-treatment and engine technologies, and a press release describing a Health Effects Institute report on the emissions reduction benefits of new technology heavy-duty diesel engines. [EMA 2012, see Appendix 1 on page 101] [HEI ACES Executive Summary] [HEI Press Release], [Khalek 2015], [Mayer 2008], [Stachulak 2014].

h) Two commenters submitted a 2012 letter to Joe Main from the public health community. This letter stated that only 30% of the underground fleet is heavy-duty permissible equipment required to install high efficiency DPM filters under 30 CFR 72.500 and 72.501, and that, without revisions to §72.502, mine operators have no incentives to introduce the most modern diesel engines and after-treatment technologies that are available for their light-duty equipment – unlike in PA, WV, and OH, where all light-duty equipment must have high efficiency DPM filters installed. This letter is discussed further under section F. [2012 letter].

14. What exhaust after-treatment technologies are currently used on diesel-powered equipment? What are the costs associated with acquiring and maintaining these after-treatment technologies and by how much did they reduce DPM emissions? How durable and reliable are after-treatment technologies and how often should these technologies be replaced?

a) One commenter stated that MSHA's diesel inventory has up-to-date data on the manufacturers and model types of DPM filters, and that MSHA should make this information available to the industry. This commenter went on to observe that manufacturers of light-duty equipment used in PA, OH, and WV can supply MSHA with cost information for DPM filters.

b) A second commenter explained that there are both paper and ceramic based filters. Paper filters are typically changed during the 100 hour maintenance of the equipment. Ceramic filters can be cleaned by burning the soot off of the filter and reused. Ceramic filter systems can last thousands of hours, and reduce emissions by 90-95%, but cost around $20,000 to install onto one piece of equipment.

c) A third commenter described having both paper filters (which must include exhaust gas cooling to be used) and ceramic based (both cordierite and silicon carbide) DPM filters in operation in Pennsylvania. This commenter stated that it will cost approximately 12,000 to 25,000 dollars to retrofit one piece of existing equipment with a DPF system. This commenter recommended including an oxidation catalyst in all DPF after-treatment systems, to greatly reduce the carbon monoxide concentration in the exhaust and burn up approximately 20 to 30 % of the organic carbon factor of DPM. This commenter stated that these are required by PA, WV and OH, are not very costly, do not require a lot of engineering to install, and if maintained properly give a great return on your expenditure.

d) A fourth commenter reported that catalytic diesel particulate filters achieve around 60% removal efficiency, last approximately 5,000 hours, and show 70-80% durability during that time. Filter replacement costs $12,000-15,000 per unit, and may involve lengthy down time while a new filter is obtained and installed (in one case over a month out of service). This commenter stated that capturable filters have better removal efficiency (e.g., 95% removal), with costs of $30,000 per unit, replacement of internal parts running $14,000 and cleaning costing $2,000 (in one case, a DPM filter costing $40,000 that was installed on a 65-ton haul truck failed to regenerate properly and had to be removed). This commenter described other problems with Tier 4 filter systems including increased maintenance costs, complex methods and timing for filter regeneration leading to an increased risk of human error and the need for technician assistance, filters not regenerating adequately, resulting in premature failures and systems shutdowns, on equipment that requires significant idling time, and the need for the engine to continue running if a re-gen is in process (about 15-20 minutes), such that, if there is a short circuit, the motor will not run and the equipment can be stuck in place.

e) A fifth commenter provided information on several strategies:

- Catalytic converters and installed dry filter systems, with a replacement cost of $12,000-$15,000 per unit and a removal efficiency of about 60%;
- Catalytic or capturable diesel particulate filters (DPFs), which cost $30,000/unit, $15,000 for filter replacement, and provide 95% removal efficiency;
- Diesel Exhaust Fluid (DEF), in addition to DPF;

- Loaders with filters that convert up to 90% of DPM to carbon dioxide and water;
- A suite of removal technologies such as DPM filters and Urea injection; or Sintered Metal Filters (which cost roughly $50,000 to purchase and install, and $6,000 annually to maintain), Diesel Filter Elements (which cost $23,500 to install and $121,000 annually to maintain), Diesel Oxidation Catalysts (which cost $17,000 to install). The latter three technologies capture anywhere from 83% to 99% of DPM;
- Upgrading from Tier 3 to Tier 4 engines or by installing Dry Systems Technology (DST) dry scrubbers on larger horsepower equipment. Upgrading from Tier 3 to Tier 4 engines costs about $16,000 per machine, but the cost may be much higher once companies account for the cost of the engine, Electronic Control Modules (ECM), and the labor associated with installation and modifications. Furthermore, the practical difficulties of replacing the engine in existing equipment persuades some companies to upgrade to Tier 4 engines only once their existing equipment is retired. Installation of DST scrubbers costs $110,000 per engine.
- The durability of the above technologies varies, but most technologies, including catalytic DPFs, Tier 4 engines, and DPM filters, need replacement or rebuilding after about 5,000 hours. DST scrubbers, however, are permanent.

f) A sixth commenter explained that those diesel exhaust filters that operate at high temperature, such as auto-regenerating ceramic filters, cannot be used on intrinsically safe equipment, a requirement for use in underground coal mines. This commenter explained that their large vehicles are fitted with water traps, and that DPM filters are installed after the water trap and must be low temperature, and able to withstand the high humidity environment created by the water trap. This commenter described a 50% exposure reduction with installation of washable filters. The company has since upgraded to fiberglass filters having 90-100% efficiency, which are three times costlier, but have a longer filter life (50 hours instead of 8 hours), reduced technician time, increased machine availability, and reduced disposal costs offsetting the higher filter costs. This commenter also described back pressure monitoring used on larger vehicles to monitor filter loading, with filter changeout at 10 kPa pressure drop across the filter.

g) This commenter also described original equipment manufacturer (OEM) retrofits at a MNM mine, with all trucks and loaders retrofitted with DPFs, and trials progressing to fit DPFs to ancillary fleet machines which do not have suitable OEM solutions. This commenter explained that truck retrofits resulted in a 66% average reduction in emissions, with newer trucks (AD60 CAT) coming equipped with DPFs. This commenter also described partial flow DPF technology, which has been trialed on light vehicles achieving an approximately 75% reduction.

h) A seventh commenter stated that MSHA should update Table 72.502-1 to reflect requirements already in place under U.S. EPA regulations on diesel engine and after-treatment technologies. When written, Section 72.502 was intended to only allow mine operators to introduce light-duty equipment with "'cleaner" engines, but Table 72.502-1 is outdated given all the advances in clean-engine technology. [Comment]

i) An eighth commenter submitted six studies that evaluate the effectiveness of after-market technologies. [Mayer 2009], [Robinson 2016], [Bugarski no date], [Stachulak 2005], [Bugarski 2009], [Bugarski 2011]

15. What are the advantages, disadvantages, and relative costs of using DPM filters capable of reducing DPM concentrations by at least 75 percent or by an average of 95 percent or to a level that does not exceed an average concentration of 0.12 milligrams per cubic meter (mg/m^3) of air when diluted by 100 percent of the MSHA Part 7 approved ventilation rate for that diesel engine? How often do the filters need to be replaced?

a) One commenter stated that all commercially available DPM filters will reduce DPM with high efficiencies which would meet Tier 4 engine standards, and that MSHA has the data on its diesel inventory to determine DPM filter efficiency with ventilation rates in order to calculate an exposure. MSHA should provide the most up-to-date data from the inventory to the industry (mine operators and miners.)
b) A second commenter stated that the costs of such systems are around $20,000 to install one of these systems onto a piece of equipment, and that these systems can reduce the emissions by around 90-95%.
c) A third commenter stated that most available filters have either 60% or 95% removal efficiency. 95% DPF have a much higher associated cost, coatings that produce increased NO2 emissions resulting in the need for additional controls, are available only on engines at Tier 3 or higher, and can create visibility issues, as these filters have to be very large to capture the exhaust of older engines. For 60% filters, operators have experienced duty cycle replacement at around 5,000 hours (approximately every 3 years), although some have reported greater difficulties with Tier III equipment, resulting in replacement at around 2000 hours. The 95% filters are fairly new, and their replacement interval is not yet known. This commenter also described an instance where a powder truck required daily filter replacement (filters were discontinued in that case).

d) A fourth commenter expressed concern regarding costs of 95% efficient filters, coatings that produce a greater amount of NO2 then peer technologies, and problems retrofitting them onto existing equipment. This commenter described filter replacement intervals of every 24 hours, every 4,500 hours, every 9-10 months, or never, with dry filter systems having less service down time, since the operators can change the filters themselves. This commenter proposed more cost-effective alternatives, such as additional ventilation and administrative controls.

e) A fifth commenter provided information on several issues [and referenced 30 CFR requirements]:

- The national coal diesel inventory shows that more than 370 heavy-duty permissible packages include filtration systems with disposable filter elements (DFEs). Over 1,140 non-permissible, heavy-duty engines are retrofitted with diesel particulate filters (DPFs) or filtration systems with DFEs to meet MSHA, PA and WV standards, and over 670 light-duty vehicles are equipped with DPFs or filtration systems with DFEs. Most require additional ventilation to meet the 2.5 g/hr standard or 0.12 mg/m^3 standard (except for a few recently certified non-permissible engines with integrated DPM controls).
- Reducing DPM emissions to 120 $\mu g/m^3$ would require additional air or a higher-efficiency filter for most engines that currently need to meet the 2.5g/hr standard. The DFEs used in underground coal mining should meet more stringent standards. One area that requires improvement is the efficiency of DFEs throughout their useful life.
- The current certification and verification procedures should be improved to accommodate the variety of deployed engines and exhaust after-treatment technologies; should detect potential secondary emissions of toxic substances; and assess both particulate mass and number concentrations.
- More stringent standards are needed to ensure that in-use emissions from diesel-powered vehicles remain close to certification levels, and to verify in-use performance of exhaust after-treatment technologies.
- Advances in portable emissions measurement systems (PEMS) allow for real-time monitoring of the currently regulated pollutants emitted by engines *(CO,* C02, NO, N02, and PM) and other pertinent engine parameters.

16. What sensors (e.g. ammonia, nitrogen oxide (NO), nitrogen dioxide (NO2)) are built into the after-treatment devices used on the diesel-powered equipment?

a) One commenter stated that carbon monoxide and temperature are the only sensors that come built into the after-treatment devices, although other sensors such as nitrogen oxide and nitrogen dioxide can be built into the system as add-ons to meet state law requirements.

b) A second commenter stated that equipment only has back pressure and temperature sensors built into the equipment, although some facilities also perform separate testing on equipment exhaust for specific contaminants. The commenter also stated that some engines with urea injection have a NOx sensor.

c) A third commenter stated that after-treatment devices do not use ammonia, nitrogen oxide, or nitrogen dioxide sensors, although one facility measures diesel exhaust for particulate matter, nitrogen oxide, and other gases with some regularity.

d) A fourth commenter stated that modern Tier 4 engines have the sensors needed to make the after-treatment system work properly as installed by the engine manufacturer.

e) A fifth commenter described Continental Automotive NOx sensors that can be used upstream and downstream of selective catalyst reduction (SCR) systems to control urea dosing and diagnose SCR systems. This commenter also described Delphi ammonia sensors for vehicles with an SCR after-treatment system that can help optimize NOx emissions.

17. Are integrated engine and exhaust after-treatment systems used to control DPM and gaseous emissions in the mining industry? If so, please describe the costs associated with acquiring and maintaining integrated systems, and the reduction in DPM emissions produced.

a) One commenter described the high costs of integrated engine and exhaust after-treatment systems. One mine company spent over $2.5 million replacing engines and dry filter systems, with a decrease of 95% per modified piece of equipment. This commenter concluded that these systems can work well, but are complex, costly, and require on-going maintenance.

b) A second commenter described costs of around $20,000 and the emission reductions of 75-95%.

c) A third commenter stated that these systems are more complex, require additional maintenance expertise, and possess more operational steps than older equipment, and thus impose higher costs, including labor costs. This commenter also described significant delays in delivery.

d) A fourth commenter stated that MSHA should share the relevant data it has on its diesel inventory.

e) A fifth commenter described Ventilation Reduction retrofits for Caterpillar engines, which incorporate selective engine hardware and software to minimize DPM in the engine exhaust, provide modern engine management systems to older engines, and are compatible with using exhaust filters and low sulfur fuel. This commenter stated that their loader fleet has been fitted with OEM DPFs in conjunction with a recent OEM ventilation reduction engine upgrade which has reduced total emissions of the loader fleet by an average of 77%. This commenter provided a table showing progressive reductions for one vehicle. [Commenter Table 2, p. 10]

18. What are the advantages, disadvantages, and relative costs of requiring that all light-duty diesel powered equipment be equipped with high-efficiency DPM filters?

a) One commenter stated that light-duty vehicles are responsible for a major fraction of the DPM burden in underground metal mines, while over 670 light-duty, nonpermissible vehicles are successfully operated in underground coal mines with high-efficiency DPFs or filtration systems with DFEs. This commenter acknowledged challenges to retrofitting existing light-duty vehicles with high-efficiency DPM filters, including lack of regeneration strategies, physical size of the systems, and higher complexity. This commenter stated that for some applications, it could be more feasible to repower vehicles with engines that meet EPA Tier 4 final standards.

b) Two commenters stated that light-duty equipment is not a significant source of DPM compared to heavy-duty equipment. These commenters noted that light-duty trucks with DPM filters produce smoke during filter cleaning and engine malfunctions, and that the filters, designed for self-cleaning at highway speeds (not mine speeds) often must be sent to the dealer for manual regeneration, leading to increased costs and down time. One of these commenters described costs of several thousand dollars for dealer servicing on a single truck, which might be required several times per year. The other noted that, for light-duty vehicles that do not have filters as standard equipment, retrofitting can be difficult because of the size of the filters required.

c) A fourth commenter stated that the primary disadvantage is cost, and that other engineering or administrative controls may be more cost effective. This commenter noted that DPM filters are not available for all mine equipment, for example buggies. This commenter suggested that Tier 4 engines could not be altered to include DPM filters and still maintain Tier 4 compliance.

d) A fifth commenter stated that the only disadvantage is the cost, around $20,000 to install on one piece of equipment, with the advantage being these systems can reduce the emissions by 95%.

e) A sixth commenter stated that if an EPA tier II engine and after-treatment system is maintained in proper operating condition, the emissions will rival the DPM output of even the newest EPA tier IV engine. This commenter presented data for a Tier II engine fitted with a 93% efficient ceramic filter, showing lower DPM emissions than a similar-sized Tier IV engine with after-treatment. This commenter suggested that installing and maintaining available systems would be simpler than replacing engines. [Data chart, p. 5]

f) A seventh commenter stated that DPM filters are feasible on all light-duty machines, and that cost information is available from manufacturers who are selling equipment in PA, WV and OH.

g) Two commenters submitted the same technical paper discussing DPM filter technology. [Khalek et al 2011]

19. In the mining industry, are operators replacing the engines on existing equipment with Tier 4i (interim) or Tier 4 engines? If so, please specify the type of equipment (make and model) and engine size and tier. Please indicate how much it costs to replace the engine (parts and labor).

a) Two commenters stated that engine replacement is often not feasible, due to configuration differences, high costs, and lack of OEM engineering support. These commenters stated that mines often switch to Tier 4 engines only when the entire piece of equipment is replaced, that increased lead time and cost are issues with Tier 4 equipment. These two commenters stated that in some cases operators have had to accept new Tier 3 equipment as replacements, for example on drilling and bolting equipment.

b) One of these commenters stated that purchasing or leasing equipment with Tier 4 engines as older equipment retires is often more cost-effective than engine replacement but can still be quite expensive, and that one mine operator estimated that replacing its existing fleet of equipment will cost tens of millions of dollars. This commenter described a mine that upgraded its Wagner loader fleet, Eimco 913 LHD fleet, and replaced forklifts, which contained Perkins engines, with Gehl forklifts. This commenter gave cost examples for installing Tier 4 engines on two existing pieces of equipment of $72,000 and $40,000.

c) This commenter stated that some Tier 4 engines are not supported by a dealer network in the company's area. This limits that company's choice of engines and its ability to source parts and technicians in its region.

d) A third commenter has a planned replacement schedule so that the majority of engines used in heavy equipment are Tier 3 and will be Tier 4 by 2020 (link to schedule (Table 1, p. 9)). For light vehicles, low emission V8 1VD engines are being purchased as replacements for 1 HZ engines (1VD engine emissions are lower emissions than 1 HZ engines fitted with DPFs); however, no Tier 4 solution is in scope for light vehicles.

e) This third commenter requires that contractors' vehicles have an EPA rated Tier 4 engine, or if a Tier 4 solution is not available an EPA Tier 3 engine retrofitted with Continuously Regenerative Trap (CRT) style diesel particulate filter (DPF).

Particulate exhaust emissions of these vehicles must be< 0.5 mg/m^3 post filtration when measured by real time analyzer or similar light scattering measurement device.

f) A fourth commenter stated that MSHA has the data on its diesel inventory and should provide the up-to-date data to the industry (mine operators and miners.)

20. What types of diesel equipment purchased new for use in the mining industry is powered by Tier 4i or Tier 4 engines? What types of diesel-powered equipment, purchased used for use in the mining industry, are powered by Tier 3, Tier 4i or Tier 4 engines?

a) One commenter stated that much equipment is gradually being replaced with Tier 4 equipment, with only a small portion replace with Tier 4 to date. Equipment affected includes trucks, loaders, excavators, drills, bolters, and powder trucks, as well as smaller equipment such as gators, welders, and generators.

b) One commenter provided examples of equipment that can be powered by Tier 4i or Tier 4 engines: Wagner loaders, the Eimco 913 LHD, Gehl forklifts, CAT wheel loaders, CAT haul trucks, some track drills, JLG's, Bobcat forklifts, and CAT 980K loaders. This commenter stated that trucks, loaders, excavators, highway truck-based units, drills, bolters, and powder trucks often have Tier 4 engines. However, new heavy equipment is not equipped with Tier 4 engines, so that the overwhelming majority of most company fleets are equipped with Tier 3 engines.

c) A third commenter stated that MSHA has the data on its diesel inventory and should provide the up-to-date data to the industry (mine operators and miners.)

21. Are Tier 4i or Tier 4 engines used in underground mines equipped with diesel particulate filter (DPF) systems (e.g., advanced diesel engines with integrated after-treatment systems)?

a) One commenter described one mine operator having all its Tier 4 engines equipped with integrated systems, a second, with all its equipment greater than 30 hp having DPF, a third, with none of its equipment having DPF systems, with other companies falling within this range. This commenter described specific equipment with Tier 4 engines and DPM filters including JLG's, forklifts, and highway-based units. Other specific examples of equipment that includes DPF are track drills, a CAT hauler truck, a CAT wheel loader, and a Komatsu wheel loader.

b) One commenter stated that many Tier 4 engines have integrated systems, but some operators meet emission requirements in other ways. For example, some

Cat Tier 4i engines use engine fueling and control technology along with an oxidation catalyst muffler.

c) A third commenter stated that MSHA has the data on its diesel inventory and should provide the up-to-date data to the industry (mine operators and miners.)

22. How long have Tier 4i or Tier 4 engines been in use in the mining industry and what additional cost is associated with maintaining equipment equipped with these engines?

a) One commenter stated that Tier 4 engines on heavy equipment in his industry have only been widely used in the past few years, while another stated that in his industry, adoption started as early as 2009 for one operator, but that most did not start adopting Tier 4 engines until the past 2 years. This commenter stated that heavy equipment with Tier 4 engines started coming online on or around 2012.

b) Two commenters stated that long-term service and maintenance costs are not yet clear in their industry, but that the systems are complex and require highly-trained technicians for service, which increases servicing costs. One of these commenters stated that the need for a CAT technician, combined with the systems complexity, led to an additional cost of $30k over a 2.5 year period for one piece of equipment with a Tier 4 engine. Another suggested that the increase in maintenance costs has been negligible.

c) Two commenters noted that service calls on equipment with the Tier 4i/Tier 4 engines are usually longer than on equipment with older engine types, and that they need to special order parts more frequently for these engines.

d) A third commenter stated that MSHA has the data on its diesel inventory and should provide the up-to-date data to the industry (mine operators and miners.)

23. What percentage of underground coal mines' total diesel equipment inventory is equipped with Tier 4i or Tier 4 engines?

a) One commenter stated that, in Pennsylvania, he/she was aware of no Tier IV engines currently being used, and that most of the fleet was made up of Tier II and Tier III engines.

b) A second commenter stated that a minority of underground diesel equipment at their MNM operations is equipped with Tier 4i or Tier 4 engines.

c) A third commenter stated that MSHA has this information on its diesel inventory and should provide the up-to-date data to the industry (mine operators and miners).

d) A fourth commenter (at a non-U.S. coal mine) stated that where possible, vehicles with older engine technology are retired. Just one Tier 1 engine loader remains in service; the majority are Tier 2 while the newer loaders have electronically controlled Tier 3 engines. Tier 4 engines presently do not meet the intrinsically safe regulatory requirements. The bulk of the diesel fleet are front-end loaders, with the majority powered by Caterpillar 3126 engines, and a smaller number by Caterpillar 3306 engine or the newer Caterpillar C9 engines. Additionally, there are a number of PJB and Drift runner personnel transport vehicles which use Perkins 1104 and 1006 engines respectively.