**WRITTEN STATEMENT
OF THE
MANUFACTURERS OF EMISSION CONTROLS ASSOCIATION
ON THE
PROPOSAL TO REVISE THE NATIONAL AMBIENT AIR QUALITY
STANDARDS FOR PARTICULATE MATTER
(DOCKET ID NO. EPA-HQ-OAR-2015-0072)**

June 29, 2020

The Manufacturers of Emission Controls Association (MECA) is pleased to provide testimony in response to the U.S. EPA's request for public comment on the Proposal to Revise the National Ambient Air Quality Standards for Particulate Matter (Docket ID No. EPA-HQ-OAR-2015-0072). MECA firmly believes that currently available emission control technologies for mobile sources can enable compliance with the most stringent standards for fine particles and inhalable coarse particles. These particulate matter (PM) and nitrogen oxides (NOx) emission control technologies for mobile sources are being used today on on-road and non-road applications in the U.S. and other major marketplaces in the world. It should be noted that technologies that reduce NOx also have an impact on PM because NOx participates in atmospheric chemistry that can result in secondary PM formation.

MECA is a non-profit association of the world's leading manufacturers of emission control technology for mobile sources. Our members have over 50 years of experience and a proven track record in developing and manufacturing emission control and efficiency technologies for a wide variety of on-road and off-road vehicles and equipment, including extensive experience in developing emission controls for gasoline and diesel engines and vehicles in all world markets. Our industry has played an important role in the emissions success story associated with mobile sources in the United States, and has continually supported efforts to develop innovative, technology-advancing, emissions programs to deal with air quality problems.

MECA will defer to the health experts to determine the appropriate $PM_{2.5}$ and $PM_{10-2.5}$ levels for the ambient standards given that they are not within our area of expertise. The Clean Air Act requires that these standards be set to protect the public health with an adequate safety margin. MECA offers comments here regarding the technological feasibility of emission control technologies for gasoline and diesel engines that are available to meet the EPA proposed standards for particulate matter and the even more stringent standards should EPA conclude that lower PM NAAQS would be needed to protect human health and welfare. A 2013 assessment by WHO's International Agency for Research on Cancer (IARC) concluded that outdoor air pollution is carcinogenic to humans, with the particulate matter component of air pollution most closely associated with increased cancer incidence, especially cancer of the lung. Respirable particulate pollution has health impacts even at very low concentrations – indeed no threshold has been identified below which no damage to health is observed. In 2005, the WHO set guideline limits aimed to achieve the lowest concentrations of PM possible. For $PM_{2.5}$ an annual limit of 10 $\mu g/m^3$ and a 25 $\mu g/m^3$ 24-hour mean were recommended.

Mobile Source Regulations that Reduce PM

The U.S. EPA has already put in place important regulatory programs for reducing PM and gaseous emissions from on-road and non-road engines and vehicles in both the light-duty and heavy-duty sectors. In addition, the establishment of the North American Emission Control Area (ECA) for ocean-going vessels that call on ports in the U.S., Puerto Rico, and U.S. Virgin Islands is projected to result in significant reductions in PM emissions. These regulatory programs rely on a systems approach that combines advanced engine technology, the use of low and ultra-low sulfur fuels, and advanced exhaust emission control technologies to achieve, in most cases, 90+% reductions in both PM and gaseous emissions compared to legacy engines and equipment.

New on-road light-duty vehicles are regulated under Tier 3 standards as well as the light-duty GHG and CAFE rules for model years through 2026. Tier 3 creates a national set of criteria pollutant standards for light-duty vehicles by largely harmonizing EPA's Tier 3 emission standards with California's LEV III emission standards, and reduced gasoline sulfur levels to a 10 ppm average across the nation by 2017. A significant difference that remains between the two light-duty regulations is that California mandates a further tightening of the PM standard under LEV III to the 1 mg/mi level beyond 2025 while EPA's Tier 3 has no such provision and retains a level three times higher, 3 mg/mile.

Heavy-duty on-highway engines are currently regulated by the 2007-2010 standards, which have resulted in DPFs being installed on all new heavy-duty on-highway diesel trucks. Heavy-duty truck fuel economy and GHG emissions are regulated via Phase 1 and Phase 2 GHG standards that fully phase in by MY 2027. California is set to propose more stringent criteria pollutant standards for heavy-duty vehicles, particularly tighter NOx limits, in August 2020. This "Omnibus" regulation will also cut the current PM limit in half, increase durability requirements, lengthen warranty periods, and add more stringent in-use testing requirements that are more representative of real-world operation. These revisions are expected to result in additional PM emission reductions throughout California. EPA has also initiated the regulatory development process for its Cleaner Trucks Initiative (CTI), which is likely to include several of the elements being considered by California, and will result in nationwide emission benefits. A harmonized CTI and California Omnibus that create a "One National Program" approach will provide the most cost-effective emission reductions and regulatory certainty to industry.

U.S. Tier 4 non-road diesel emission regulations that have been phased in over the 2008-2015 timeframe have resulted in DPF installation on only about 40% of non-road engines. Europe has implemented Stage V non-road standards in 2019 that include a particle number limit stringent enough to require DPFs on all non-road engines with power between 19-560 kW. India adopted the same requirements under their Bharat

Stage (CEV/TREM) IV - V emission standards for nonroad diesel engines used in construction and agricultural equipment beginning in 2024. China's Stage IV NRMM standards that begin implementation in 2020 include a PN limit that aligns with the EU and India but further require a DPF be installed on all 37-560 kW non-road engines.

Recognizing the progress made around the world to reduce PM emissions from non-road engines and equipment, in 2020 California has noted its intention to initiate a test program to demonstrate the feasibility to reduce NOx and PM limits on non-road engines in support of future national standards for non-road diesel engines. This program is likely to draw from the on-highway regulations currently in development. More stringent limits for non-road engines could be achieved with currently available technologies and would result in cost-effective emission benefits.

Exhaust Emission Technologies to Reduce PM and NOx Emissions from Diesel Engines

Due to the long operating lives of many diesel engines, it will take many years for older, "dirtier" on-road and non-road diesel engines to be replaced with the mandated newer "cleaner" engines. Given the health and environmental concerns associated with older diesel engines and because older, existing on-road and non-road diesel engines make up a significant percentage of diesel pollution emitted, there has been interest in retrofitting the existing legacy fleet of on-road and non-road diesel engines as a means of complying with federal or state ambient air quality standards for PM and ozone. MECA believes that proven retrofit technologies are available to deliver significant reductions in PM and NOx emissions from existing on-road and non-road diesel engines. Effective regulatory and/or incentive programs will be needed at the local, state, and federal levels to accelerate the clean-up of older diesel engines through the use of verified retrofit technologies or replacement with newer, cleaner engines.

A number of advanced emission control technologies exist today to significantly reduce PM and NOx emissions from new and existing diesel engines, and most of these are playing a major role in complying with current EPA emission standards for new engines. These include closed crankcase filters (CCF), diesel oxidation catalysts (DOC), diesel particulate filters (DPFs), selective catalytic reduction (SCR), NOx adsorber catalysts, and exhaust gas recirculation (EGR). In addition, several proven technologies that have not yet made significant penetration into the diesel engine market, but could do so if more stringent limits are set, include cylinder deactivation, advanced turbochargers, and several advanced aftertreatment designs.

Diesel Particulate Filters – Diesel particulate filters (DPFs) are the most effective PM reduction technology for a wide range of diesel engine applications. High-efficiency DPF technology can reduce PM emissions by up to 90 percent or more, ultra-fine black carbon particles by up to 99+ percent and, toxic HC emissions by up to 80 percent or more. Millions of on-road heavy-duty vehicles and hundreds of thousands of off-road pieces of equipment have been retrofitted with passively or actively regenerated DPFs worldwide. In addition, MECA members have verified a variety of DPF retrofit technologies with both EPA and CARB. The durability and performance of PM control technologies has been demonstrated on OEM heavy-duty, on-road applications since the 2007 model year when nearly every new medium-duty and heavy-duty diesel vehicle sold in the U.S. or Canada has been equipped with a high efficiency diesel particulate filter to comply with the U.S. EPA's 2007/2010 heavy-duty highway emission regulations. This represents more than two million trucks operating with DPFs here in North America. DPFs have been standard equipment on new heavy-duty trucks in Europe starting from 2013 and China this year (2019 in major cities) in order to comply with the Euro VI and China VI, respectively, diesel particle number emission standards. A number of manufacturers have also started to equip a range of off-road diesel engines with DPFs to comply with EPA's Tier 4 off-road emission standards.

These advanced wall-flow DPFs not only capture soot particles in the $PM_{2.5}$ range, they are also very effective at capturing over 99+% of ultrafine particles. Ultrafine particles in the less than 20 nanometer size range contribute almost nothing to the overall mass of PM in the exhaust however; they may represent a huge number of particles with an extremely high surface area. Numerous health studies have shown that these ultrafine particles may pose the greatest adverse health effects due to their high surface area that can attract volatile toxic compounds and their ability to penetrate deep into the lungs. Although ultrafine particles are not currently regulated, they are the topic of extensive research and discussion among the health community. MECA published a report that summarizes research on health impacts due to exposure to ultrafine particles titled "Ultrafine Particulate Matter and the Benefits of Reducing Particle Numbers in the United States" (http://www.meca.org/resources/MECA_UFP_Report_0713_Final.pdf). Co-benefits of DPFs include the capture or oxidation of the majority of ash, carbonaceous or volatile ultrafine particles in the exhaust, and significant reductions to black carbon emissions, an important short-lived climate pollutant.

It is important to note the several manufacturers of off-road diesel engines have introduced Tier 4 final-compliant off-road diesel engines that will not employ DPFs to meet Tier 4 final PM standards. Instead these manufacturers will utilize advanced diesel combustion strategies and SCR catalysts to meet Tier 4 final off-road PM and NOx standards. These non-DPF equipped off-road diesel engines will likely have significant ultrafine PM emissions compared to DPF-equipped engines. Additional work will be needed to characterize the health effects of new diesel engines not equipped with high efficiency DPFs. MECA believes that EPA needs to explore additional PM regulatory measures for new off-road diesel engines to ensure the use of best available PM filtering technology. These additional regulatory measures may include additional tightening of the PM mass-based emission standards for these engines, or the adoption of particle number-based emission standards as has been done in Europe, China and India for light-duty and heavy-duty diesel engines and vehicles.

Development work is ongoing to further enhance the performance of filter system designs. For example, work continues on developing and implementing additional filter regeneration strategies that will expand the applications for retrofitting DPFs. Increased durability requirements and tighter PM limits to 5 mg/bhp-hr in CARB's current proposed on-road heavy-duty Omnibus rule, and likely to be included in EPA's CTI, drive continued development work on filter materials and designs to further enhance filter system durability. This proposed PM limit is comfortably above the capability of today's DPF technology that typically reports certification levels less than 10% of the required standard. The 50% reduction in PM standard being proposed in these rules is primarily designed to prevent backsliding on PM in the presence of more stringent NOx limits proposed by these rules. In addition, fuel economy and GHG standards are spurring ongoing development to further reduce backpressure.

Diesel Oxidation Catalysts (DOCs) – DOC technology is available today and represents a cost-effective PM control strategy. This proven technology has been employed for decades and has been installed on hundreds of millions of on- and off-road engines worldwide. Control efficiencies of 20 to 50 percent for PM, up to 90 percent reductions for carbon monoxide (CO) and hydrocarbon (HC), including large reductions in toxic hydrocarbon species have been achieved and reported in tests of DOCs on a large variety of on-road and non-road diesel engines. With respect to particulate emissions, the wide range of PM reductions observed with DOCs reflects the fact that DOCs oxidize the soluble hydrocarbons, or soluble organic fraction (SOF) associated with PM. The SOF content of PM contains several toxic compounds, such as polycyclic aromatic hydrocarbons (PAH), and is related in part to the oil consumption characteristics of diesel engines.

Selective Catalytic Reduction (SCR) Technology **–** SCR is a proven, durable NOx reduction technology for mobile sources and has become an important NOx emission reduction technology for mobile sources in the U.S. and other world markets as evidenced by the hundreds of thousands of light-duty and heavy-duty vehicles that have been sold and operated with SCR technology for decades in Europe, Japan, and North America. SCR is being used by most engine manufacturers for complying with U.S. EPA's on-road and non-road heavy-duty diesel engine emission standards. Several auto manufacturers have also commercialized SCR systems for light-duty diesel vehicles that are being sold across the U.S.

MECA recently published two white papers that provide detailed information on technology feasibility and cost-effectiveness for future NOx emission regulations. The first paper focuses on achieving a 0.05 g/bhp-hr limit beginning with model year (MY) 2024 engines through the use of current system architectures and the latest generation of commercial catalysts hardware (http://www.meca.org/resources/MECA_MY_2024_HD_Low_NOx_Report_061019.pdf). The second paper focuses on achieving a 0.02 g/bhp-hr limit on the current certification cycles and the ability to meet a future limit on a new test cycle that represents low load operation beginning with MY 2027 engines (http://www.meca.org/resources/MECA_2027_Low_NOx_White_Paper_FINAL.pdf).

Manufacturers continue to improve SCR substrates in order to increase geometric surface area, allow uniform catalyst coating, reduce back pressure on the engine, and reduce thermal mass. As OEMs gained experience with engine calibration, catalyst suppliers made improvements to the performance and reduced manufacturing costs. More efficient packaging for thermal management and efficient urea mixing designs have allowed the systems to be reduced in size by over 60% while achieving lower NOx emissions than first generation systems. The cost of a heavy-duty truck has increased at approximately 1% per year (https://theicct.org/publications/costs-emission-reduction-technologies-heavy-duty-diesel-vehicles) while the cost of emission controls has declined, making emission controls a smaller fraction of new truck cost. Due to the combination of cost savings realized since 2010, as well as the cost reductions expected before new standards are implemented in 2024 and 2027, we estimate that the emission controls needed to meet future 0.02 g/bhp-hr NOx standards in 2027 will cost about the same or less than MY 2010 systems. In full size engine testing at Southwest Research Institute that began in 2015, these advanced aftertreatment technologies have demonstrated the ability to convert over 98% of the NOx to harmless nitrogen and water over all operating modes and duty cycles.

Several MECA member companies have proven experience in the installation of SCR systems for both stationary and mobile engines, as well as the installation of integrated DPF+SCR emission control systems for combined PM and NOx reductions. A number of off-road diesel retrofit demonstrations have been done with combination DPF+SCR retrofit systems. Applying SCR to diesel-powered engines provides simultaneous reductions of NOx, PM, and HC emissions and retrofit manufacturers have verified DPF+SCR or DOC+SCR retrofit systems for both on-road and off-road applications. In some of these applications, DPF+SCR equipped retrofit systems have achieved over 80% NOx reduction. There are hundreds of DPF+SCR retrofit devices operating on medium- and heavy-duty on-road vehicles in Europe and the U.S. Although important differences exist between on-road and off-road diesel applications, many of the same manufacturers develop similar systems for OEM on-road and off-road applications. The experience from on-road applications are typically carried over into more challenging off-road vehicles.

Passive NOx Adsorber Technology **–** One technology that has evolved specifically to address cold-start NOx emitted at low exhaust temperatures beginning at room temperature, includes a family of new materials referred to as passive NOx adsorbers (PNA). This catalyst technology is used upstream of the traditional exhaust control system, in combination with the DOC, to trap and store NOx at temperatures between room temperature and 200°C before urea can be dosed into the hot exhaust. Once the exhaust temperature is sufficient for SCR catalysts to convert NOx to nitrogen, and to allow the urea dosing system to be activated, the NOx stored on the PNA begins to desorb so it can be converted by the ammonia reductant over the downstream SCR catalyst. This emerging technology was demonstrated in the Stage 1 CARB low NOx demonstration program and has been discussed in several SAE technical papers (e.g., SAE paper no. 2017-01-0958; SAE paper no. 2017-01-0954). PNA technology may be one of the strategies available to engine and vehicle manufacturers to achieve lower cold-start tailpipe NOx levels.

Crankcase Emission Controls – Crankcase emissions from diesel engines can be significant and can be controlled by the use of a multi-stage filter designed to collect, coalesce, and return the emitted lube oil to the engine's sump. Filtered gases are returned to the intake system, balancing the differential pressures involved. Typical systems consist of a filter housing, a pressure regulator, a pressure relief valve and an oil check valve. These systems have the capability to virtually eliminate crankcase emissions. This technology is currently being used in Europe and the U.S. on a variety of new diesel engines, as well as in the United States on a retrofit basis. Closed crankcases with filtration systems are required on new heavy-duty on-road and non-road diesel engines as part of EPA's regulatory programs covering these applications.

Engine Technologies to Reduce PM and NOx Emissions from Diesel Engines

The calibration of internal combustion engines is a delicate balance that has to deal with trade-offs to optimize performance and emissions. For example, there is an inverse relationship between PM and NOx emissions that engine manufacturers applied to meet emission standards up through the 2006 heavy-duty highway regulations. In 2007, the requirement to reduce both PM and NOx emissions caused OEMs to install diesel particulate filters (DPF) on diesel vehicles, which allowed engine calibrators to optimize the combustion in the engine to meet lower NOx emissions while relying on the DPF to remediate the resulting higher PM emissions. This example of effective emission regulations provided a technology solution to overcome the traditional barriers of engine calibration. In 2010, SCR systems were installed on most trucks in response to a further tightening of NOx limits. SCR allowed calibrators to not only reduce the soot load on DPFs (and in turn provide a better NOx to soot ratio to promote passive soot regeneration) as a way of improving fuel efficiency but also to take advantage of another well-known trade-off in combustion thermodynamics between fuel consumption (or CO_2 emissions) and NOx emissions from the engine. A few of the types of on-engine technologies that directly reduce fuel consumption and reduce PM and NOx from the engine or indirectly facilitate engine calibration to reduce engine out emissions of PM and NOx are discussed below.

Advanced Turbochargers – Turbochargers are used by heavy-duty engine OEMs to improve fuel efficiency and reduce emissions. Turbochargers also make it possible to downsize the engine to further reduce fuel consumption without sacrificing peak torque and power. A turbo can increase engine power by pumping air into the combustion chambers at higher-than-atmospheric pressure, which allows more fuel to be burned, resulting in higher output. A typical turbo is driven by exhaust gases by routing these gases through a turbine. The turbine is attached to a shaft which has a compressor mounted on the opposite end. Engine exhaust rotates the shaft at speeds above a hundred-thousand rpm, which in turn compresses the air entering the engine's intake manifold. Because the act of compressing air results in the air heating, which is undesirable, intercoolers are commonly installed with turbos. The latest high efficiency turbochargers are one of the more effective tools demonstrated on the DOE SuperTruck program.

In addition to affecting the power density of the engine, turbochargers play a significant role in PM, NOx and CO_2 regulations compliance. Continuous improvement in turbocharger technology is making it possible to run very lean combustion (high air/fuel ratios) which is fast and efficient. This allows for very low particulate generation and even low engine-out NOx. In addition, these highly efficient turbochargers affect the pumping loop in such a way that they can provide positive crankshaft work and improve brake specific fuel consumption (BSFC) and brake specific CO_2 ($BSCO_2$) as intake manifold boost pressure becomes higher than exhaust manifold backpressure.

Modern turbochargers have a variety of available technology options enabling lower CO_2 emissions by improving thermal management capability, such as: i.) state of the art aerodynamics, ii) electrically-actuated wastegates that allow exhaust gases to by-pass the turbo to increase the temperature in the aftertreatment, and iii.) ball bearings to improve transient boost response. These and other technologies are available to support further reductions in CO_2 and emissions. More advanced turbochargers are designed with a variable nozzle that adjusts with exhaust flow to provide more control of intake pressure and optimization of the air-to-fuel ratio for improved performance (e.g., improved torque at lower speeds) and fuel economy. These variable geometry turbochargers (VGT), also known as variable nozzle turbines (VNT) and variable turbine geometry (VTG), also enable lower CO_2 emissions through improved thermal management capability to enhance aftertreatment light-off. Finally, modern turbochargers have enabled engine and vehicle manufacturers the ability to downsize engines, resulting in fuel savings without sacrificing power and/or performance.

Cylinder Deactivation – Cylinder deactivation (CDA) is an established technology on light-duty vehicles, with the primary objective of reducing fuel consumption and CO_2 emissions. This technology combines hardware and software computing power to in effect “shut down” some of an engine’s cylinders, based on the power demand, and keep the effective cylinder load in an efficient portion of the engine map without burning more fuel by reducing the number of cylinders firing during lower load operation. The technology uses solenoids on the valve lifters to keep intake and exhaust valves closed when a cylinder is deactivated while simultaneously shutting off fuel to the deactivated cylinder. Rather than pumping cold intake air into the exhaust system during coasting or idling, the valves are closed, allowing the deactivated cylinder to act as a spring as the piston moves up and down the bore. Closing the valves eliminates most of the normal pumping losses that reduce the engine fuel efficiency and thermal energy due to cold air being pumped through the exhaust.

Deactivating a portion of the cylinders causes the remaining active pistons to work harder within a more efficient part of the engine operating regime, thus increasing fuel economy and generating more heat to get the aftertreatment hot faster. In addition, shutting off an engine’s cylinders during deceleration and idling reduces air flow through the engine and exhaust to enable heat retention in the exhaust system. Both of these conditions, enabled by CDA, improve the SCR’s ability to effectively reduce NOx emissions. During low load operation, CDA has resulted in exhaust temperatures increasing by 50°C to 100°C when it is most needed to maintain effective conversion of NOx in the SCR. In some demonstrations, CDA has been combined with a 48V mild hybrid motor with launch and sailing capability to extend the range of CDA operation over the engine, and this may deliver multiplicative CO_2 reductions from these synergistic technologies.

Electrification – Electrified powertrains are quickly making their way from light-duty passenger cars to commercial trucks and buses. The technology level of electrification and penetration rate can vary across weight classes and vocations, but the conclusion that electrified powertrains are an effective tool to reduce CO_2 as well as criteria pollutants is being recognized by regulators and vehicle manufacturers. There are numerous examples of electric and electrified commercial vehicles being offered for sale and demonstrated by virtually all of the OEMs. Suppliers anticipate that electrification will play a more significant role in helping OEMs meet future NOx and GHG standards.

Various levels of electrification are available, and some are more suited for certain types of vehicle applications and duty cycles. The configurations range from mild hybrids to strong/full hybrids to plug-in hybrids to full battery and fuel cell electric. In all of the configurations that still include an engine, various components are likely to be electrified in future engines and vehicles. These include electric turbos, electronic EGR pumps, AC compressors, electrically heated catalysts, electric cooling fans, oil pumps and coolant pumps among others.

Emission Technologies to Reduce PM Emissions from Gasoline Engines

A mechanism for secondary PM creation that is primarily associated with gasoline engines involves the reaction between volatile hydrocarbon (VOC or ROG) species and sunlight in the atmosphere to form secondary organic aerosol (SOA). SOA is often comprised of ultrafine particulates that undergo changes in the atmosphere, resulting in contribution to regional haze and a reduction in visibility. Hydrocarbon precursors to SOA formation can be emitted from the tailpipe or volatilized from the fuel system of gasoline vehicles. The technology base of advanced three-way catalysts, exhaust hydrocarbon adsorber materials, high cell density substrates, emission system thermal management strategies, secondary air injection systems, advanced carbon canisters, advanced low fuel permeation materials, and air intake hydrocarbon adsorber materials that have already been commercialized for PZEV gasoline vehicle applications can be extended to and further optimized to allow all light-duty, medium-duty, and heavy-duty gasoline vehicles to achieve the exhaust and evaporative emission reduction needed by vehicle manufacturers to comply with LEV III/Tier 3 light-duty, medium-duty, and heavy-duty vehicle exhaust and/or evaporative emission standards.

Over the past five years, engine and exhaust control advances have made PM reductions, including tighter particle number standards more cost effective and thus achievable much earlier than 2025. For context, a particle number standard of 6×10^{11} particles per kilometer, which is roughly equivalent to 0.5 mg/mile, has been adopted by the European Union, China and India for implementation in 2017, 2020 (2019 in major cities) and 2023, respectively. The European light-duty GDI particle number limit in conjunction with the adoption of real-world driving emission (RDE) requirements for light-duty vehicles has led European auto manufacturers to introduce cleaner technologies, such as advanced fuel injection systems and GPFs, in order to comply with these regulations. Nearly all auto manufacturers that sell into the European market are working with MECA members on applications of GPFs on GDI vehicles. Many of the same US manufacturers that are selling vehicles in the U.S. currently manufacture GPF models for Europe. In turn, European manufacturers with models that use GPFs to meet the European particle number limit export similar models to the U.S. with no GPFs on U.S. versions of those vehicles. As the European Union continues to strengthen its particle number and real-driving emission regulations, it is likely that GPFs will be installed on light-duty vehicles with PFI engines as well.

Gasoline particulate filters (GPFs) are based on the same, wall flow ceramic filters that have been successfully applied on millions of light-duty diesel vehicles in Europe and the U.S. for 20 years. The performance and application of these gasoline particulate filters has been highlighted in a number of recent technical publications in both the U.S. and Europe (e.g., SAE paper no. 2016-01-0941; *Emission Control Science and Technology*, DOI: 10.1007/s40825-018-0101-y; *Reducing Particulate Emissions in Gasoline Engines*, https://www.sae.org/publications/books/content/r-471/). Like diesel particulate filters, gasoline particulate filters are capable of reducing particle emissions by more than 85% over a wide range of particle sizes, including high capture efficiencies for ultra-fine particulates and inorganic ash-based particulates. Recent work, funded by MECA at the University of California-Riverside CE-CERT labs, characterized the toxic compounds from two GDI vehicles with and without GPFs (*Environmental Science & Technology*, DOI: 10.1021/acs.est.7b05641). Specifically, we looked at polycyclic aromatic hydrocarbons (PAHs), nitro-PAHs and ultrafine metal oxide particles and found that GPFs reduce over 90% of the ultrafine metal particles and over 99% of the solid PAH compounds in the GDI PM. The studies also showed that GDI engines emit 2-5 times more PAH compounds than conventional PFI vehicles and the high levels of gaseous PAH compounds emitted from GDIs were reduced by 55-65% from these two vehicles when GPFs were installed.

The application of a GPF on a four cylinder gasoline direct injection vehicle is expected to cost approximately $100, making this emission control technology a cost effective solution for reducing particulate emissions from future gasoline vehicles. When these filters are properly designed, the impact of a GPF installation on the backpressure and fuel efficiency of the vehicle is expected to be minimal. EPA needs to make sure that these same ultra-low PM, Euro 6 GDI engines/technologies are also utilized in the U.S. EPA and California have a long history of setting technology advancing vehicle standards and this leadership needs to continue with respect to light-duty vehicle particle emission standards.

Inspection and Maintenance

Periodic inspection and maintenance (I/M) tests are critical to a comprehensive vehicle emissions reduction strategy. While many states have light-duty I/M programs, only California currently has a statewide heavy-duty I/M. An opacity test is an inexpensive, simple measurement that should be an integral part of a proactive preventative maintenance program for heavy-duty trucks. Programs like California's HDVIP and PSIP, which include opacity tests, provide safeguards that DPFs are working in the field and ensure that vehicles meet applicable exhaust emission standards under normal operating conditions. CARB is developing a more comprehensive heavy-duty I/M program that will monitor NOx and PM emissions through the OBD system relying on sensors that are already on trucks today. In 2018 CARB amended their heavy-duty OBD requirements to include Real Emissions Assessment Logging that will record in-use NOx emissions and store it in the OBD control unit. Having this information on-board trucks will help ensure real-world compliance and facilitate future I/M capability for trucks.

The Netherlands and Germany have already started programs that would eventually lead to the adoption of mandatory new periodical technical inspection (NPTI) emission testing requirements. NMI, the Dutch metrology institute, has released a draft International Recommendation with the specifications of the PTI particulate number counter. A test procedure and correlation would have to be developed to allow for these compact instruments to be used for compliance purposes. The test is likely to be a 30 second measurement at low idle speed as a way to confirm the DPF/GPF has not been compromised.

These programs can require significant investments in labor and equipment, as well as in trained personnel to conduct the emissions test, but the investments can be recouped through inspection fees and health benefits. An I/M program is the most effective way to ensure that emission controls are maintained and remain on vehicles and continue to function properly to deliver the expected emission benefits. This will have the added co-benefit of better performance and longer engine life, therefore reducing the total cost of ownership.

Conclusion

In closing, we believe that there are proven gasoline and diesel engine emission control technologies available for achieving significant reductions in PM emissions, as well as NOx emissions, from new and existing on-road and non-road engines, vehicles and equipment. These technologies are required by tighter emission standards for mobile sources and can be used in regulatory or voluntary-based programs at the state and U.S. federal level to help achieve the most stringent ambient particulate matter standards under discussion by EPA experts and others. Once appropriate health-based standards are in place, our industry is prepared to do its part and deliver these cost-effective, advanced emission control technologies to the market.

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