COMMENTS FROM MECA CLEAN MOBILITY ON THE PROPOSAL TO RECONSIDER THE NATIONAL AMBIENT AIR QUALITY STANDARDS FOR PARTICULATE MATTER (DOCKET ID NO. EPA-HQ-OAR-2015-0072)

March 28, 2023

MECA Clean Mobility (MECA) is pleased to provide testimony in response to the U.S. EPA's request for public comment on the Proposal to Reconsider 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 assist states with 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 technologies for clean mobility. Our members have nearly 50 years of experience and a proven track record in developing and manufacturing emission control, engine efficiency, battery materials, components and charging equipment as well as electric propulsion technology for a wide variety of on-road and off-road vehicles and equipment in all world markets. Our industry has played an important role in the emissions success story associated with light-, medium- and heavy-duty vehicles in North America, and has continually supported efforts to develop innovative, technology advancing, emission reduction programs to improve ambient and local urban air quality while reducing greenhouse gases.

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 2021, the WHO set guideline limits aimed to achieve the lowest concentrations of PM possible. For $PM_{2.5}$ an annual limit of 5 $\mu g/m^3$ and a 15 $\mu g/m^3$ 24-hour mean were recommended. There were significantly lower than WHO's 2005 guidelines of 10 μg/m^3 and 25 μg/m^3 for the annual and 24-hour averages.[1]

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. It is widely anticipated that EPA's forthcoming rule "Multi-Pollutant Emission Standards for Model Years 2027 and Later Light-Duty and Medium-Duty Vehicles" will revise the PM standard to be equal to or more stringent than CARB.

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. Both California (in 2021) and EPA (in 2022) recently finalized more stringent criteria pollutant standards, particularly tighter NOx limits, for heavy-duty vehicles starting with model year 2024 in California and 2027 federally. The regulations also cut the current PM limit in half, increased durability requirements, lengthened warranty periods, and added more stringent in-use testing requirements that are more representative of real-world operation. These regulations will result in additional primary and secondary PM emission reductions throughout the U.S.

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

[1] https://www.who.int/news-room/feature-stories/detail/what-are-the-who-air-quality-guidelines

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 includes 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, California recently initiated a test program to demonstrate the feasibility to reduce NOx and PM limits on non-road engines in support of future state and national standards. This program is drawing from experience with demonstrations of on-highway vehicles that supported the recent updates to heavy-duty vehicle emission standards. More stringent limits for non-road engines could be achieved with currently available technologies and would result in cost-effective emission reductions.

Emission Technologies to Reduce PM Emissions from Gasoline Engines

Direct PM Emission Control

Over the past five years, engine and exhaust control advances have made direct PM reductions below 1 mg/mile, including tighter particle number standards, more cost effective and thus achievable much earlier than 2025 as required under LEV 3. 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 gasoline direct injection (GDI) vehicle 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 gasoline particulate filters (GPF), 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.

Fuel injection technology has been advancing with suppliers achieving injection pressures up to 800 bar. This increased injection pressure provides two main benefits to an engine: 1) reduced PM emissions; and 2) reduced fuel consumption. For example, increasing injection pressure to 500 bar provides up to 50% lower particle number emissions along with a 1% reduction in fuel consumption and thus CO_2 emissions. Higher injection pressures achieve these benefits because they facilitate better fuel dispersion and mixing of air and fuel in cylinder, resulting in more complete combustion of fuel. The better mixing reduces deposit formation on injector tips as well as cylinder surface, and deposit formation leads to increased PM emissions[2].

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 (see DPFs on page 5 of this document). 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[3][4][5]. 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[6]. 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 more than the current three-way catalysts, 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 has been shown 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.

MECA recently conducted a study to model the benefits of a PM standard set at 0.5 mg/mile, with the assumption that this is approximately equivalent, on a mass basis, to particle number standards in other global automotive regions. In regions such as Europe, China and India, these lower standards are already being met by the deployment of best available fuel injection and GPF technology. In our analysis, potential 2027 and later PM emission limits were defined for the federal test procedure (FTP), cold-temperature FTP, and supplemental FTP (SFTP) for all complete vehicle certifications through 14,000 lbs. GVWR. The study also considered three different rates of

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[2] https://wiener-motorensymposium.at/en/papers/1216d5f3-5904-46fd-8e53-efd3a7083a60?returnUrl=https%253A%252F%252Fwiener-motorensymposium.at%252Fliteratursuche%253Fseite%253D26&cHash=f8b062579821a73c0ebd58bb862b3d16

[3] SAE paper no. 2016-01-0941

[4] *Emission Control Science and Technology*, DOI: 10.1007/s40825-018-0101-y

[5] *Reducing Particulate Emissions in Gasoline Engines*, https://www.sae.org/publications/books/content/r-471/

[6] *Environmental Science & Technology*, DOI: 10.1021/acs.est.7b05641

electrification as detailed in Table 1. A national modeling framework was developed from the EPA's 2016v2 Modeling Platform[7] to examine state-aggregate impacts of fine particulate matter (PM2.5) and black carbon (BC) from exhaust. The EPA's MOVES model (version 3.04[8]) was applied to interpolate and extrapolate the modeling period out to the study's horizon year of 2060. The platform was modified, for instance, to update the list of states (i.e., Clean Air Act Section 177 states) which have adopted California most recent Advanced Clean Cars II (ACC II) motor vehicle standards[9]. A regulatory control case was added to the MOVES model which included revised temperature-exhaust adjustment algorithms and regulation-specific exhaust basic emission rates. Exhaust basic emission rates were modeled over the full-service life of vehicles including assumptions of control technology performance and malfunction.

Table 1. Modeling Study Rate of Electrification Assumption Scenarios

Domain	Electrification Case		
	AEO2022	**Mid Range**	**High Range**
Section 177 States Following CARB ZEV Mandate	AEO projections assigned to CA+177 States based on 2019 MY sales; CA+177 state share of national EVs increased linearly to 85% by MY2030 and held at 85% thereafter.	Modification of the High Range case assuming that 100% electrification will not be met until MY2050.	California ACC II regulation plus linear growth to achieve 100% electric by MY2040; passenger car electrification occurs more quickly than LDT.[10]
Balance of United States (Federal Certification Region)	AEO national projections less vehicles assigned to CA+177 states.	50% of national total sales electrified by MY2035 (5 years after Biden Executive Order); linear growth thereafter to reach 100% electrification by MY2060.	Biden Executive Order of 50% of national total sales electrified by MY2030; linear growth thereafter to reach 100% electrification by MY2050; passenger car electrification occurs more quickly than LDT.

Results from this modeling study are summarized in Figure 1 (a and b) below. The blue and green lines on each plot show the modeled cumulative PM and black carbon (BC) emission reductions from the combustion vehicle fleet, respectively, for a given year after implementation of a 0.5 mg/mile PM standard that begins with vehicle model year 2027. Figure 1a predicts cumulative PM reductions of 120,000 tons from ICE vehicles in the presence of modest EV adoption per the AEO2022 electrification forecast. A high electrification forecast in combination with more stringent PM limits on ICE vehicles are modeled in Figure 1b. The magnitude of PM reductions from combustion vehicles subjected to a stringent PM limit are roughly equivalent to the reduction achieved through electrification at high rates of penetration over the study period.

[7] https://www.epa.gov/air-emissions-modeling/2016v2-platform
[8] https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves
[9] https://ww2.arb.ca.gov/our-work/programs/advanced-clean-cars-program/advanced-clean-cars-ii
[10] Automobile electrification rate about twice that of light-duty trucks as observed in historic AEO data; faster automobile electrification also agrees with qualitative summary of ARB's ACC II.

Restated another way, these results demonstrate that cleaner engine-powered vehicles and electric vehicles are complementary in reducing PM emissions by approximately equal magnitudes.

Figure 1a. Projected benefits from clean ICE vehicles – AEO2022 EV forecast

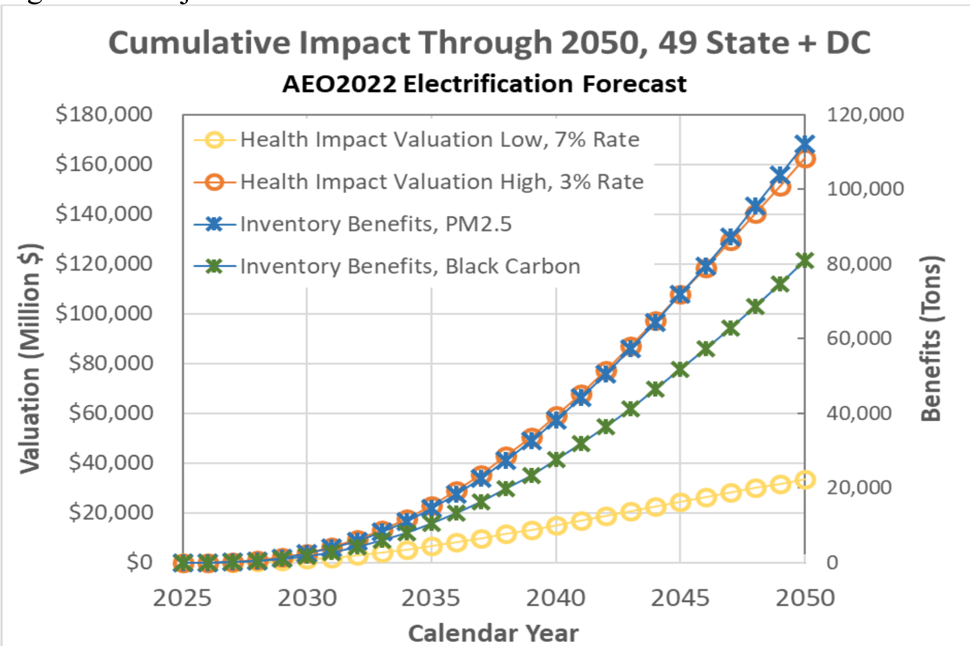

Figure 1b. Projected benefits from clean ICE vehicles – high EV forecast

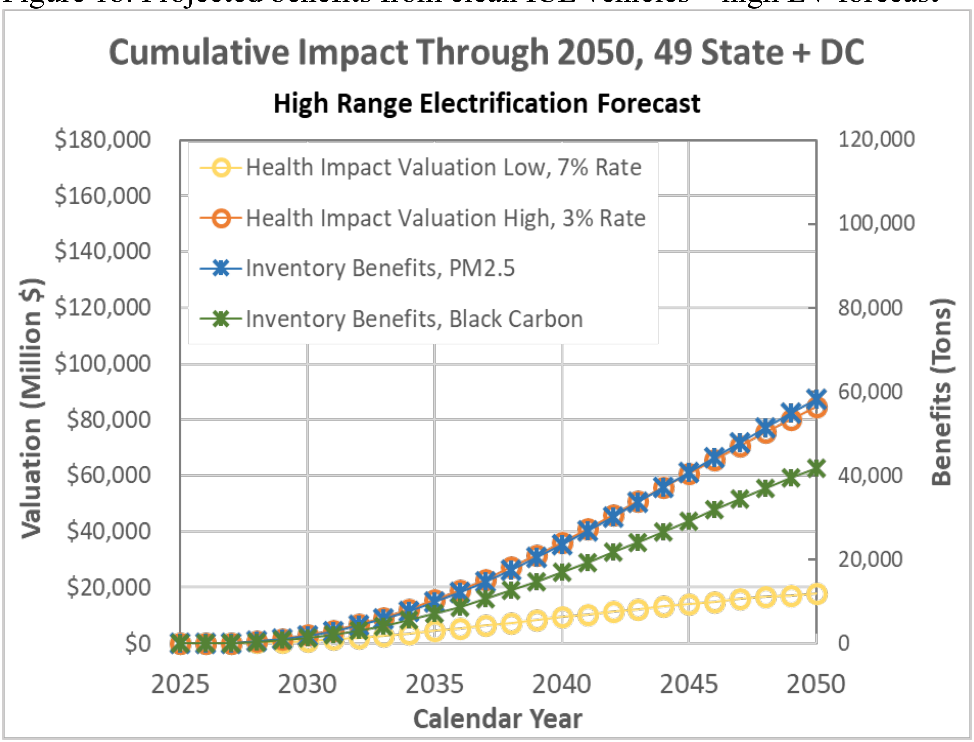

Figure 1 includes monetized health benefits (left axis) calculated with EPA's reduced form tools for calculating PM2.5 benefits[11]. Based on the modeled PM reductions and application of two different discount rates (3% and 7%), the health impact valuation in Figure 1a ranges from $35B to $160B. The health valuation due to PM emissions reduced by emission controls on engine-powered vehicles in a high electrification scenario (Figure 1b) ranges from $20B to $80B. These health benefits are roughly five times the incremental cost of implementation of the emission control technologies that would yield the PM reductions.

Figure 1 also displays the resulting reductions in black carbon emissions based on the application of best available control technologies on passenger cars and light trucks. Black carbon particles have high surface area and low mass, so a small mass of black carbon could lead to disproportionately large climate and health impacts. In fact, black carbon has a global warming potential that can be several thousand times that of an equivalent mass of CO_2 based on a 20-year basis[12]. Fortunately, best available mobile source emission control technologies can reduce black carbon emissions by up to 99%, which results in benefits to human health while mitigating climate change.

Secondary PM Emission Control

A mechanism for secondary PM creation that is primarily associated with gasoline engines involves the reaction between volatile or semi-volatile hydrocarbon (VOC or ROG) species with sunlight and other compounds in the atmosphere to form secondary organic aerosol (SOA). SOA is often comprised of ultrafine particulates that undergo physical and chemical 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. These emissions can be efficiently controlled by the technology base that have already been commercialized for PZEV gasoline vehicle applications. Exhaust hydrocarbons are reduced by advanced three-way catalysts, exhaust hydrocarbon adsorber materials, high cell density substrates, emission system thermal management strategies, and secondary air injection systems. Research has demonstrated that application of catalyzed gasoline particulate filters on gasoline direct injection vehicles resulted in significant reduction in the production of SOA. This is likely due to reduction of the reactive hydrocarbon precursors included in the primary organic aerosol[13].

Evaporative hydrocarbon emissions are controlled with advanced carbon canisters, advanced low fuel permeation materials, and air intake hydrocarbon adsorber materials. Further technology optimization would 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 the most stringent light-duty, medium-duty, and heavy-duty vehicle exhaust and/or evaporative emission standards included in

[11] https://www.epa.gov/benmap/reduced-form-tools-calculating-pm25-and-ozone-benefits
[12] https://19january2017snapshot.epa.gov/www3/airquality/blackcarbon/2012report/fullreport.pdf
[13] https://doi.org/10.1021/acs.est.8b06418

CARB's recently finalized ACC II and EPA's forthcoming proposed regulation for light and medium-duty vehicles.

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 is a need in making sure that the legacy fleet is maintained through state run inspection and maintenance programs (I/M). Additional emission benefits result from incentivizing fleets to retire legacy vehicles and replace them with 2010 and newer trucks that have the full complement of emission controls such as DOCs, DPFs and SCR that reduce PM and NOx emissions by over 90%. Effective regulatory and/or incentive programs such as U.S. EPA's DERA grant program will be needed at the local, state, and federal levels to accelerate the replacement of older diesel 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), and exhaust gas recirculation (EGR). In addition, 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 mechanically and electrically driven turbochargers, electric catalyst heaters and advanced aftertreatment designs.

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 mass and number emissions by up to 90 percent or more, black carbon, a short-lived climate forcing pollutant, by up to 99 percent and, toxic HC (including polycyclic aromatic hydrocarbons) 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. 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. DPFs have been standard equipment on new heavy-duty trucks in Europe starting from 2013 and China since 2020 (2019 in major cities) in order to comply with the Euro VI and China VI, respectively, diesel particle number emission standards. Several engine manufacturers have also equipped a range of non-road diesel engines with DPFs to comply with EPA's Tier 4 non-road emission standards. However, as will be discussed below, the majority of Tier 4 non-road engines do not employ DPFs.

Manufacturers of non-road diesel engines have introduced Tier 4 final-compliant 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. These non-DPF equipped non-road diesel engines will likely have significant ultrafine PM emissions compared to DPF-equipped engines. MECA believes that EPA needs to explore additional PM regulatory measures for new non-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, as is currently being discussed by CARB in recent workshops on a Tier 5 standard. We encourage EPA and CARB collaboration on future stringent standards that would advance best available emission control technology on non-road engines.

Development work is ongoing to further enhance the performance of filter system designs. Increased durability requirements and tighter PM limits to 5 mg/bhp-hr in recently finalized EPA and CARB heavy-duty engine regulations drive continued development work on filter materials and designs to further enhance filter system durability. This finalized PM limit is comfortably above the capability of today's DPF technology that typically reports certification levels less than 10% of today's required 10 mg/bhp-hr standard. The 50% reduction in PM standard finalized by these rules is primarily designed to prevent backsliding on PM in the presence of more stringent NOx limits.

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.

In 2019-2020, MECA 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[14]. The second paper focuses on achieving 90% lower emissions from today's limit on the current certification cycles and the ability to maintain efficient emission controls during low load operation, beginning with MY 2027 engines[15]. In full size engine testing at Southwest Research Institute that began in 2015, these advanced aftertreatment technologies have demonstrated the ability

[14] http://www.meca.org/resources/MECA_MY_2024_HD_Low_NOx_Report_061019.pdf
[15] http://www.meca.org/resources/MECA_2027_Low_NOx_White_Paper_FINAL.pdf

to convert over 98% of the NOx to harmless nitrogen and water over all operating modes and duty cycles and maintained this high efficiency to extended durability periods finalized by CARB and EPA regulations.

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[16] while the cost of emission controls has declined, making emission controls a smaller fraction of new truck cost. Both CARB and EPA provided detailed cost analyses in their Omnibus and Clean Trucks Plan rulemakings, respectively (Table 2). The agencies concluded that costs for engine and aftertreatment emission controls to meet new standards would be reasonable and lead to cost-effective benefits.

Table 2. Cost Estimates for Hardware to Achieve EPA Low-NOx Standards at Longer Durability

Source	Incremental Cost
EPA	\$3,200 - \$3,900
MECA	\$3,500 - \$4,800
CARB	\$8,478 (for CARB's Omnibus)

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 are discussed below. It is expected that the 2024 CARB and 2027 EPA truck regulations will create opportunities for engine manufacturers to deploy advanced engine technologies such as driven turbos, cylinder deactivation, and mild hybrid architectures to

[16] https://theicct.org/publications/costs-emission-reduction-technologies-heavy-duty-diesel-vehicles

complement advanced aftertreatment technologies such as heated mixers and dosers, close-coupled NOx catalysts and SCR coated PM filters.

Advanced Driven Turbochargers – 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.

Driven turbochargers can be used to control the speed of the turbomachinery independently of the engine's exhaust flow and vary the relative ratio between engine speed and turbo speed. Driven turbochargers may be utilized for several reasons, including performance, efficiency, and emissions. Considered an "on-demand" air device, a driven turbocharger also receives transient power from its turbine. During transient operation, a driven turbocharger will behave like a supercharger and consume mechanical or electrical energy to accelerate the turbomachinery for improved engine response. At high-speed operation, the driven turbocharger will return mechanical or electrical power to the engine in the form of turbo-compounding, which recovers excess exhaust power to improve efficiency. This cumulative effect lets a driven turbocharger perform all the functions of a supercharger, turbocharger, and turbo-compounder. NOx emission control uniquely benefits from the application of driven turbochargers in several ways, including the ability to decouple EGR from boost pressure, reduce transient engine-out NOx, and improve aftertreatment temperatures during cold start and low load operation.

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

Electrification strategies can be applied to engine platforms regardless of fuel with the result being an elimination of tailpipe emissions. Hybrid and now full battery electric passenger car sales have been increasing at a fast pace, and 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, such as PM and NOx, is being recognized by regulators and vehicle manufacturers. There are numerous examples of electric and electrified vehicles being offered for sale and demonstrated by virtually all of the light- and heavy-duty OEMs. Suppliers anticipate that electrification will play a more significant role in helping OEMs meet future criteria pollutant 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 configurations that still include an engine, various components are likely to be electrified in future vehicles. These include electric turbos, electronic EGR pumps, AC compressors, electrically heated catalysts, electric cooling fans, oil pumps and coolant pumps among others.

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 program. An opacity test is an inexpensive, simple measurement that has been 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. Now that new vehicles include on-board diagnostics (OBD), CARB has recently implemented a more comprehensive heavy-duty I/M program that allows vehicle owners to periodically report information from the OBD system rather than conduct testing. Owners may also have data collected remotely from the vehicle via telematics, which further reduces burden on the driver and/or vehicle owner. In 2018 CARB amended their heavy-duty OBD requirements to include Real Emissions Assessment Logging that will record in-use NOx and CO2 emissions recorded from sensors already on current trucks 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, Belgium, Germany and Switzerland have adopted mandatory periodical technical inspection (PTI-PN) particulate filter testing programs. NMI, the Dutch metrology institute, developed requirements for the specifications of the PTI particulate number counter. Several instruments have been approved or are in the process of certification. A test procedure and correlation have been developed to allow for these compact instruments to be used for compliance purposes. The test takes 90 seconds and confirms that 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 reduction benefits. This will have the added co-benefit of better performance and longer engine life, therefore reducing the total cost of ownership. I/M is the most effective way to ensure that the engines and aftertreatment are maintained in order to reduce PM emissions from legacy vehicles that will make up a large portion of the fleet for decades.

Conclusion

In closing, we believe that there are proven gasoline and diesel engine emission controls as well as electrification technologies available for achieving significant reductions in direct PM emissions. Furthermore, there is an opportunity to reduce PM from light- and medium-duty vehicles by setting stringent standards that will ensure best available control technologies are applied to these vehicles in the U.S. Secondary PM formation can also be reduced by reducing precursors such 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. The reduction of PM and NOx from mobile sources has been an effective tool for the past 50 years to help states achieve their PM NAAQS compliance goals.

Once appropriate health-based standards are in place, our industry is prepared to do its part and deliver these cost-effective, electric and advanced emission control technologies to the market.

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