# MOBILE SOURCE TECHNOLOGIES TO REDUCE GREENHOUSE GAS EMISSIONS

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## 1.0 INTRODUCTION

Anthropogenic activities, particularly the burning of fossil fuels, have changed the composition of the atmosphere in ways that threaten dramatic changes to the global climate. Signs of climate change are evident worldwide and additional changes will have serious impacts on our nation's future. Although transportation is a vital part of the economy and is crucial for everyday activities, it is also a significant source of greenhouse gas emissions. Some of the important greenhouse gas emissions from fossil fuel combustion from mobile sources include: carbon dioxide ($CO_2$), nitrous oxide ($N_2O$), methane ($CH_4$), and black carbon. Climate change is also impacted negatively by higher ground level ozone emissions. Ozone levels are in turn linked to hydrocarbon and NOx emissions from mobile and stationary sources.

Since the beginning of the industrial revolution, concentrations of $CO_2$ have increased by nearly 30%, methane concentration have more than doubled, and nitrous oxide concentration have increased by approximately 15%. Emissions from the transportation sector contribute about 33% of the $CO_2$ emissions in the U.S. and account for 96% of the radiative forcing effect from transportation sources. A majority of anthropogenic $CO_2$ emissions come from the combustion of fossil fuels. Despite improvements in vehicle engine efficiency, transportation energy use is expected to grow by 48% between 2003 and 2025. As such, controlling greenhouse gas (GHG) emissions from the transportation sector is essential to the overall efforts to alleviate long-term impacts on the climate. There are a large set of technologies that can significantly reduce, either directly or indirectly, mobile source emissions of $CO_2$, $N_2O$ (as well as other NOx emissions), $CH_{4,}$ and black carbon.

## 2.0 CARBON DIOXIDE ($CO_2$)

As the largest source of U.S. greenhouse gas emission, $CO_2$ from fossil fuel combustion has accounted for approximately 79% of global warming potential (GWP)-weighted emissions since 1990, growing slowly from 77% of total GWP-weighted emissions in 1990 to 80% in 2006. Of the total, transportation activities accounted for 33% of the U.S. $CO_2$ emissions from fossil fuel combustion in 2006. The overall rise in U.S. GHG emissions primarily reflects increased emissions of $CO_2$ as a result of increasing fossil fuel combustion. Over 60% of the $CO_2$ emissions resulted from gasoline consumption for personal vehicle use and the remaining emissions came from other transportation activities, including combustion of diesel fuel in heavy-duty vehicles. In 2003, about 81% of transportation GHG emissions in the U.S. came from on-road vehicles, with light-duty vehicles accounting for 62% of total transportation emissions. Heavy-duty vehicles were responsible for 19% of total transportation emissions and nonroad vehicles accounted for 16% of all transportation GHG emissions in 2003. There are a large set of technology combinations that are available to reduce greenhouse gas emissions from passenger vehicles and light-duty trucks, including fuel efficient, state-of-the-art and future advanced gasoline and diesel powertrains. Many of these fuel efficient powertrains also have applicability in heavy-duty vehicle applications and powertrains used in off-road applications.

Implicit in federal and state greenhouse emission analyses is the ability of these advanced powertrain options to meet the applicable criteria pollutant emission standards, such as CO, NOx, and non-methane organic gases (NMOG). All of these advanced, powertrain options combined with the appropriately designed and optimized emission control technologies can meet all current and future federal and state criteria emission requirements. In this manner, advanced emission controls for criteria pollutants enable advanced powertrains to also be viable options for reducing greenhouse gas emissions. A range of powertrain technologies, including engine turbochargers, advanced exhaust gas recirculation technologies, advanced direct injection fuel systems, variable valve actuation technology, advanced transmissions, hybrid powertrain components, and powertrain control modules, can be applied to both gasoline and diesel powertrains to help improve overall vehicle efficiencies and reduce fuel consumption, both of which can result in lower $CO_2$ exhaust emissions.

Light-duty diesel powertrains will see increased interest in North America because of their high fuel efficiency and relatively lower greenhouse gas emissions compared to gasoline engines (on the order of 20-40% higher fuel efficiency and 10-20% lower $CO_2$ emissions for diesel engines compared to comparable gasoline engines). Fuel consumption advantages of diesel engines are especially important during higher speed engine/vehicle operations that are consistent with highway driving. In contrast, hybrid electric powertrains see lower fuel consumption primarily during lower speed vehicle operations that are more associated with urban driving. MECA believes that any regulatory requirements associated with greenhouse gas emissions should be based on real-world driving or usage patterns in order to ensure that regulatory standards reflect actual vehicle operations and deliver the greenhouse gas emission reductions that are needed. Vehicle manufacturers and emission control technology manufacturers need a valid test cycle for greenhouse gas emission to engineer and evaluate vehicles consistent with how they are used by the public. The weighting of the test cycle between urban and highway driving modes will have a significant influence on the choice of powertrain options that will be used to meet any future greenhouse gas emission or fuel economy standards.

Advanced emission controls for controlling diesel particulate emissions and NOx emissions from diesel engines allow light-duty diesel engines to achieve comparable criteria pollutant emission levels to gasoline engines. Significant criteria emission reductions from diesel vehicles can be achieved through the use of several technologies, including diesel particulate filters and catalyst technologies designed to reduce NOx emissions in lean combustion exhaust. Additional details on these advanced emission control technologies are provided below.

*Diesel Particulate Filters (DPFs)*

Diesel particulate filters (DPFs) remove particulate matter in diesel exhaust by filtering exhaust from new and existing diesel engines. DPFs can achieve up to, and in some cases, greater than, 90% reduction in diesel particulate matter (PM). The basis for the design of wall-flow particulate filters is a ceramic honeycomb structure with alternate channels plugged at opposite ends. As the gases pass into the open end of a channel, the plug at the opposite end forces the gases through the porous wall of the honeycomb channel and out through the neighboring channel. The porous wall and the filter cake of particulate matter that forms within and on the surface of the wall serve as the filter media for particulates. Since the filter can fill up over time by developing a layer of retained particles on the inside surface of the porous wall, the accumulated particles must be burned off or removed to regenerate the filter. This regeneration process can be accomplished with a variety of methods including both active strategies that rely on generating external sources of heat (e.g., fuel burners, fuel dosing strategies that utilize fuel combustion over a catalyst, electrical elements, intake air throttling) and passive strategies that utilize catalysts that are displayed directly on the filter element or upstream of the filter.

In addition to wall-flow ceramic particulate filters, exhaust filters are also available based on metal substrates that utilize sintered metal filtering elements and tortuous flow paths for directing the particulate-containing exhaust gases through the sintered filter element.

To date, more than five million DPFs have been installed on light-duty diesel vehicles operating in Europe. New "clean diesel" light-duty models that are already available in the U.S. or will be introduced in the coming years will be equipped with DPFs to meet EPA or ARB mass-based emission standards for diesel PM. Nearly all new heavy-duty diesel engines starting with the 2007 model year in the U.S. are equipped with diesel particulate filters to comply with EPA's mass-based emission standards for diesel PM. Future off-road diesel engines are also expected to make use of diesel particulate filters to comply with EPA's Tier 4 off-road diesel engine PM standards that begin their phase-in starting in 2011. In addition to these new engine applications of diesel particulate filters, retrofit diesel particulate filters have been successfully applied to more than 250,000 existing diesel engine worldwide. These retrofit filters that include both passively and actively regenerated designs provide significant reductions in harmful diesel PM from the large legacy fleet of diesel engines used for both highway and off-road applications. Additional information on diesel particulate filters can be found in MECA reports on www.meca.org that highlight exhaust emission control technologies for new diesel engines and diesel retrofit emission control technologies.

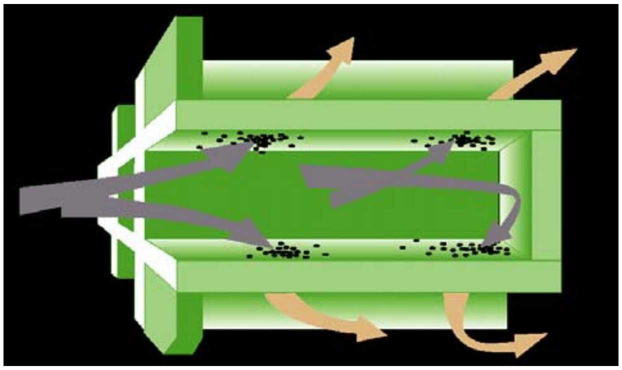


**Diagram of a Wall-flow Diesel Particulate Filter**

*Selective Catalytic Reduction (SCR) and Lean NOx Adsorber Catalysts for Diesel Engines*

Selective catalytic reduction (SCR), lean NOx adsorber catalysts and combinations of these two technologies can be used to significantly reduce NOx emissions from diesel vehicles. SCR systems use a chemical reductant, usually a urea/water solution, to convert nitrogen oxides to molecular nitrogen in oxygen-rich exhaust streams like those encountered with diesel engines. Upon thermal decomposition in the exhaust, urea decomposes to ammonia which serves as the reductant. As exhaust and reductant pass over the SCR catalyst, chemical reactions occur that reduce NOx emissions to nitrogen and water.

Lean NOx adsorber catalysts have characteristics similar to the catalytic converters used on gasoline, stoichiometric engines but with the addition of materials that adsorb NOx under typical lean engine operations. As the lean NOx adsorber catalyst fills up with adsorbed NOx, a short oxygen deficient or fuel rich regeneration cycle is needed to displace the adsorbed NOx and reduce the NOx over available precious metal catalyst sites using hydrocarbon and CO reductants that are available during this rich regeneration step. These lean NOx adsorber catalysts can also adsorb SOx species that may be present in the exhaust and therefore require ultra-low sulfur levels in the fuel to maximize their performance for reducing NOx. In addition to frequent short NOx adsorber regeneration cycles, these catalysts must also be less frequently purged of adsorbed sulfur species.

SCR catalyst and lean NOx adsorber catalysts for diesel combustion strategies are capable of reducing NOx emissions from 70 to 90%. SCR catalysts are already widely used on late model trucks operating in Europe to control NOx (> 500,000 trucks) and will be used by most heavy-duty engine manufacturers to comply with EPA's 2010 heavy-duty, on-road NOx emission standards. SCR technology's ability to achieve high NOx conversion efficiencies has allowed heavy-duty engine manufacturers to make use of engine calibration strategies that are optimized for higher engine-out NOx levels that provide lower engine fuel consumption. As an example, U.S. 2010-compliant heavy-duty engines that will employ DPF+SCR systems are expected to provide 3-5% lower fuel consumption (and lower greenhouse gas emissions) compared to engine designs that will make use of higher exhaust gas recirculation (EGR) levels and DPFs to meet equivalent emission levels.

Lean NOx adsorber catalysts have already seen applications on a few light-duty diesel vehicles sold in Europe and Japan and will be used on smaller new "clean diesel" light-duty diesel engines that will be available here in the U.S. The 2009 model year VW Jetta includes a lean NOx adsorber catalyst system for achieving EPA's Tier 2, Bin 5 and California's LEV II LEV NOx emission standards. The 2007 Dodge Ram pick-up, powered by a Cummins diesel engine, became the first heavy-duty vehicle to meet EPA's 2010 on-road, heavy-duty emission standards (three years in advance of the 2010 standards) by using an advanced emission control system that featured a diesel particulate filter and a lean NOx adsorber catalyst.

An early version of Mercedes' BlueTec technology combined a lean NOx adsorber catalyst with a SCR catalyst on the Mercedes E320 sedan first offered for sale in the U.S. in October 2006. Honda has reported on its efforts to combine lean NOx adsorber catalysts with SCR catalysts on the same substrate for future light-duty diesel vehicles that will be sold in the U.S. and Japan. These combined NOx adsorber/SCR systems rely mostly on the NOx adsorber catalyst for NOx reductions with the SCR catalyst serving as a NOx "clean-up" catalyst. Ammonia is produced during the regeneration of the NOx adsorber catalyst and can then be used by the SCR catalyst as an internal source of reductant without the need for external urea injection ahead of the SCR catalyst.

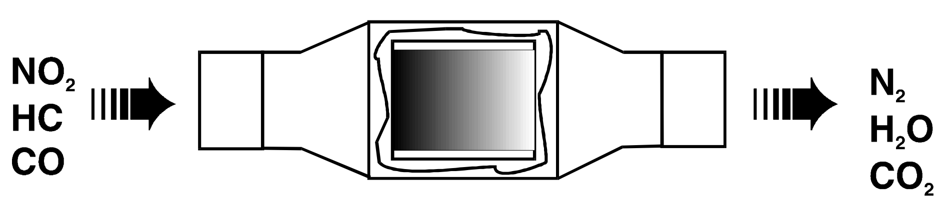
In the future, SCR or lean NOx adsorber catalysts may be coated directly on diesel particulate filter substrates to allow for simultaneous removal of all four important criteria pollutants from diesel exhaust: hydrocarbons, CO, NOx and diesel PM. Toyota has already pioneered the application of lean NOx adsorber catalysts coated on wall-flow ceramic filter substrates with limited commercial applications in Europe and Japan. Catalyst manufacturers are already working to optimize systems that place SCR catalysts directly on wall-flow filter substrates. These combined NOx/PM technologies offer the potential for more compact emission control systems that could provide lower exhaust system backpressures and further improvements in overall engine efficiencies.

*Gasoline Direct Injection Technology*

For gasoline vehicles, direct fuel injection technology enables gasoline engines to achieve greater fuel efficiency. In a gasoline direct injection engine, gasoline is directly injected into the cylinder the same way as in a diesel engine. Gasoline direct injection permits more fine-tuned control of the amount of fuel injected as well as control of injection timing independently from valve timing. Gasoline direct injection engines can reduce $CO_2$ emissions in a number of ways, including better "breathing" efficiency, higher engine compression ratio, the potential for lean operation and reduction of pumping losses. Gasoline direct injection offers $CO_2$ emissions reductions ranging from 5% to 20% depending on how it is implemented and the base engine to which it is compared. Again emissions controls ensure that these more fuel efficient gasoline engines meet tough EPA or ARB criteria emission regulations:

- Under stoichiometric conditions, a three-way catalyst can significantly reduce emissions of NOx, HC and CO. The use of three-way catalyst allows for simultaneous conversion of HC, CO, and NOx produced during the combustion of fuel in a spark-ignited engine. Three-way catalyst reduces these air pollutants by up to 99+ percent. The active catalytic materials are present as thin layers on the internal walls of a ceramic or metallic honeycomb substrate. The substrate typically provides a large number of parallel flow channels to allow for sufficient contact area between the exhaust gas and the active catalytic materials without creating excess pressure losses. In 2005, 100% of new cars sold in the U.S. were equipped with a catalytic converter, and worldwide over 90% of new gasoline cars sold came equipped with a catalytic exhaust emission control device.

**Three-Way Converter**



- Under lean combustion conditions, similar emission control technologies used on diesel vehicles can be used to reduce emissions from lean, gasoline direct injection powertrains. These include particulate filters to reduce PM emissions, and SCR and/or lean NOx adsorber catalysts to reduce NOx emissions.

As stated previously, lean NOx adsorber catalyst performance has a high degree of sensitivity to fuel sulfur levels. The current U.S. EPA fuel sulfur limits for gasoline (30 ppm average, 80 ppm cap) are too high to allow lean NOx adsorber catalysts to be a viable NOx control strategy for fuel efficient, gasoline lean-burn engines that employ direct fuel injection technology. Lower gasoline fuel sulfur limits in the U.S. would allow NOx adsorber catalysts to be used on such vehicles and provide manufacturers and consumers with additional options for reducing greenhouse gas emissions from gasoline vehicles. NOx adsorber catalysts are already commercially used on gasoline lean-burn light-duty vehicles in Europe and Japan because these markets have gasoline fuel sulfur levels available with a maximum sulfur limit of 10 ppm. California will begin to enforce a 20 ppm fuel sulfur cap on gasoline beginning in 2012. A U.S. national gasoline sulfur cap in the range of 10-20 ppm is needed to allow fuel efficient, lean combustion gasoline engines to make use of NOx adsorber catalyst technology to comply with California or EPA criteria emission limits.

Diesel-electric and gasoline-electric hybrid vehicles, that combine either a diesel or gasoline engine with elements of an electric-drive powertrain, offer a range of $CO_2$ emission reduction possibilities, and again advanced emission controls allow these powertrains to meet even the toughest criteria emission regulations. Exhaust emission controls for gasoline and diesel engines are also generally compatible with low carbon, alternative fuels (e.g., gasoline blends with renewable ethanol or biodiesel blends) that can provide additional reductions in mobile source greenhouse gas emissions. However, it is important that specifications associated with any low carbon fuel should be compatible with the use of available engine and exhaust emission control technologies.

## 3.0 BLACK CARBON

Black carbon is a major component of particulate matter emissions from mobile sources and is believed to have a significant net atmospheric warming effect by enhancing the adsorption of sunlight. Black carbon is a mix of elemental and organic carbon emitted by fossil fuel combustion, bio-mass burning, and bio-fuel cooking as soot. Black carbon is a dominant absorber of visible solar radiation in the atmosphere. Anthropogenic sources of black carbon are transported over long distances and are most concentrated in the tropics where solar irradiance is highest. Because of the combination of high absorption, a regional distribution roughly aligned with solar irradiance, and the capacity to form widespread atmospheric brown clouds in a mixture with other aerosols, emissions of black carbon are thought to be the second strongest contribution to climate change after $CO_2$ emissions. According to scientists at the Scripps Institute of Oceanography and University of Iowa, soot and other forms of black carbon could have as much as 60% of the current global warming effect of carbon dioxide. Black carbon plays a major role in the dimming of the surface and a correspondingly large solar heating of the atmosphere. For example, the retreat of the Himalayan-Hindu Kush glaciers is one of the major environmental problems facing Asia. The glacier retreat has accelerated since the 1970s and several scientists have speculated that solar heating by soot in atmospheric brown clouds and deposition of dark soot over bright snow surfaces may be an important contributing factor for the acceleration of glacier retreat. In addition, black carbon at high altitudes can trap and retain energy reflected off of clouds below and inside the cloud formations. In this way, black carbon allows clouds to absorb even larger amounts of energy that comes from the sun or is reflected back from the earth (i.e., black carbon can lower the albedo or reflectivity of clouds). A recent study published in a 2009 issue of *Nature Geoscience* (vol. 2, 2009) by researchers from the NASA Goddard Institute and Columbia University found that black carbon is responsible for 50% of the total Arctic warming observed from 1890 to 2007 (most of the observed Arctic warming over this timeframe occurred from 1976 to 2007).

Diesel particulate matter emissions account for 30% of black carbon globally and 50% in the U.S. It is estimated that 70% of the black carbon emissions from mobile sources are from diesel-fueled vehicles, with the assumption that 40% of gasoline PM is black carbon and 60% of diesel PM is black carbon. Up to 25% of the carbon footprint of a heavy-duty diesel truck is associated with black carbon exhaust emissions. Since black carbon particles only remain airborne for weeks at most compared to carbon dioxide, which remains in the atmosphere for more than a century, removing black carbon can have an immediate benefit to both global warming and public health. The black carbon concentration and its global heating will decrease almost immediately after reduction of this emission. In addition, technology that can substantially reduce black carbon emissions associated with the combustion of carbon-based fuel already exists in the form of commercially available particulate filters.

Black carbon from diesel vehicles can be significantly reduced through emission control technology. High efficiency diesel particulate filters (DPFs) on new and existing diesel engines provide nearly 99.9% reductions of the black carbon emissions associated with soot. During the regeneration of DPFs, captured carbon is oxidized to $CO_2$ but this filter regeneration still results in a net climate change benefit since the global warming potential of black carbon has been estimated to be about 2,000 times higher than that of $CO_2$ on a per gram of emissions basis. As noted previously, essentially all new on-road, heavy-duty diesel engines have been equipped in the U.S. and Canada with high efficiency DPFs to comply with EPA's and Environment Canada's 2007 standards for diesel particulate matter. The DPFs installed on these new heavy-duty diesel engines are estimated to reduce PM emissions by more than 100,000 tons per year. It is estimated that installing a high efficiency DPF on all existing diesel vehicles operating in the world today would achieve a reduction equivalent to a 17.4% reduction in global $CO_2$ levels. Even the use of partial flow filters on mobile sources with 50% reduction efficiency for particulate emissions can provide significant impacts on climate change through reductions in black carbon.

Because older diesel engines emit significant amounts of PM, there are significant opportunities to reduce black carbon emissions through diesel retrofit programs that make use of retrofit DPF technology. The number of vehicles retrofitted, the number of programs, and the interest in new program for DPFs has grown significantly over the past few years with more than 250,000 DPFs installed as retrofits to date in a variety of world markets. Retrofit filters can provide large health and climate change benefits through reductions in diesel particulate and black carbon emissions on existing, on-road and off-road diesel engines.

Since EPA's latest set of emission standards for new diesel engines (light-duty, on-road, off-road, commercial marine, and locomotive) have set technology-forcing PM standards that will largely be met through the use of diesel particulate filters, policy makers in the U.S. should focus attention on strategies for encouraging or requiring the use of retrofit filters on existing diesel engines as a means of not only providing health-based benefits but also climate change benefits associated with black carbon reductions. As an example, these co-benefits could be obtained by mandating the use of filters on existing stationary diesel engines that are used for back-up power generation or pumping applications in the U.S. EPA estimates that there are approximately 900,000 of these stationary diesel engines in operation across the country. Mandatory particulate matter reductions could also be considered for goods movement activities in a manner similar to the regulatory actions that California has adopted as part of its Diesel Risk Reduction Plan. State and local agencies can encourage filter retrofits on diesel construction equipment by adopting best available control technology provisions in public construction contracts. New York City's Local Law 77 is an example of a local agency requiring the use of ultra-low sulfur diesel fuel and best available retrofit control technology on equipment used on publicly funded construction projects. Other jurisdictions have made use of construction project contract provisions that requires the use of clean construction equipment and includes funding to clean-up equipment as part of the contract. Examples of contract provisions that include the use of clean construction equipment are available at: http://www.epa.gov/otaq/diesel/construction/contract-lang.htm.

If mandates are not workable, then federal and state governments should consider providing significant financial grants or loan programs that would provide more wide scale opportunities for retrofitting the millions of existing diesel engines that operate today in the U.S. with filter technologies. As an example, the current Diesel Emissions Reduction Act (DERA) included in the 2005 Energy Act was authorized at $200 million per year for five years but has only seen appropriations of about $50 million in FY 2008 and $60 million in FY 2009, with an additional $300 million provided in 2009 through the economic stimulus package approved by Congress and signed by President Obama. Funding in excess of $100 billion would be needed to retrofit the more than 10 million diesel engines currently operating in the U.S. with high efficiency filters.

## 4.0 NITROUS OXIDE ($N_2O$)

While total $N_2O$ emissions are much lower than $CO_2$ emissions, $N_2O$ is approximately 310 times more powerful than $CO_2$ at trapping heat in the atmosphere. One of the main anthropogenic activities producing $N_2O$ in the U.S. is fuel combustion in motor vehicles. In 2006, $N_2O$ emissions from mobile source combustion were approximately 9% of total U.S. $N_2O$ emissions. It is estimated that the $N_2O$ emissions account for about 2% of the total GHG emissions from a typical light-duty vehicle. $N_2O$ is emitted directly from motor vehicles and its formation is highly dependent on temperature and the type of emission control system used.

Temperatures favorable for $N_2O$ formation are achieved inside catalytic converter systems, especially during cold-start conditions when engine exhaust temperatures are lower.

Catalyst efficiency and age are also important factors in $N_2O$ formation. At higher efficiencies and lower ages, $N_2O$ formation is lower. In addition to direct $N_2O$ emissions, NOx emissions from mobile and stationary sources have a significant impact on atmospheric $N_2O$ levels. On late model light-duty gasoline vehicles, modern three-way catalyst-based emission control technology combined with effective cold-start engine calibration strategies are very effective at controlling vehicle nitrous oxide emissions. Light-duty vehicle $N_2O$ emission tests results recently published by ARB and Environment Canada in *Atmospheric Environment* (vol. 43, 2009) indicate that vehicles certified to the lowest emission certification categories (e.g., certified to ARB's SULEV standards) also have extremely low $N_2O$ emissions (in the range of 0.0-1.5 mg/km).

Tightening of vehicle hydrocarbon and NOx emission standards over time with the parallel introduction of more effective emission control systems have resulted in lower emissions of $N_2O$ from today's vehicles compared to older vehicles certified to less stringent hydrocarbon and NOx standards. The performance of NOx emission control technologies for diesel vehicles such as SCR catalysts and lean NOx adsorber catalysts can also be optimized to minimize $N_2O$ emissions from diesel engines.

## 5.0 METHANE ($CH_4$)

According to the United Nation's International Panel on Climate Change (IPCC), methane is more than 20 times as effective as $CO_2$ at trapping heat in the atmosphere. Over the last 250 years, the concentration of $CH_4$ in the atmosphere has increased by 148%. Methane is a byproduct of imperfect fuel combustion. Methane emissions from mobile sources are emitted from the exhausts of vehicles using hydrocarbon fuels, but the anthropogenic contribution of road transport to the global methane inventory is less than 0.5%. Emissions of $CH_4$ are a function of the type of fuel used, the design and tuning of the engine, the type of emission control system, the age of the vehicle, as well as other factors. Although $CH_4$ emissions from gasoline vehicles are small in terms of global warming potential when compared to $N_2O$ emissions, they can be high in natural gas-fueled vehicles, as methane is the primary component of natural gas.

On light-duty gasoline vehicles, modern three-way catalyst-based emission control technology is effective at reducing all hydrocarbon exhaust emissions including methane. Tightening of hydrocarbon emission standards over time with the parallel introduction of more effective emission control systems have resulted in lower emissions of methane from today's vehicles compared to older vehicles certified to less stringent standards. Catalyst designs can also be optimized in concert with engine control strategies to oxidize methane exhaust emissions from motor vehicles including vehicles that operate exclusively on natural gas or bi-fuel vehicles that can operate on either natural gas or gasoline.

## 6.0 GROUND-LEVEL OZONE

There is a significant linkage between ground level ozone concentrations and climate change impacts. One example was detailed by a group of researchers from the United Kingdom in a 2007 *Nature* publication. In this work, ground-level ozone was shown to damage plant photosynthesis resulting in lower carbon dioxide uptake from plants that have been exposed to higher levels of ozone. Other studies have shown that increasing average annual temperatures are likely to result in even higher levels of ozone in the environment. According to the National Oceanic and Atmospheric Administration (NOAA), concentrations of ozone have risen by around 30% since the pre-industrial era. Ozone in the troposphere (middle altitudes between the ground and the stratosphere) acts as a potent greenhouse gas by capturing heat much as carbon dioxide does. In fact, pound for pound, ozone is about 3,000 times stronger as a greenhouse gas than $CO_2$. Tropospheric ozone is considered by the IPCC to be the third most important greenhouse gas after carbon dioxide and methane. An additional complication of ozone is that it also interacts with and is modulated by concentrations of methane.

Emission reductions aimed at lowering ambient ozone levels, such as lower emissions of volatile organic compounds (VOCs) and NOx, will have a positive impact on climate change, as well as human health. Policies that aim to reduce ambient ozone levels may also become more necessary and important to either mitigate the climate change impacts of ground level ozone or to mitigate higher ozone levels that result from climate change. To that end, EPA's future actions on climate change must still include strategies that will provide lower ambient ozone levels across the U.S. Earlier in 2008, EPA revised the national ambient air quality standard for ozone downward and states will be challenged to put together implementation plans for meeting these new ozone standards in the coming years. Even though EPA has finalized aggressive criteria emission standards for many mobile source categories that began their implementation in this decade and continue into the next decade, there are still opportunities for further reductions in hydrocarbon and NOx emissions from new and existing mobile source categories that should be a part of the tools that EPA can offer states for meeting the existing and future ozone standard that will be driven by climate change and human health impacts.

A significant opportunity for reducing hydrocarbon and NOx emissions from existing light-duty vehicles could be seized if EPA would follow California's lead on setting tighter performance and durability requirements for aftermarket three-way catalytic converters that are sold for replacement applications on light-duty cars and trucks. Starting in 2009, California requires higher emission performance levels and a 50,000 mile durability requirement for aftermarket converters, while EPA still relies on a policy set in 1986 that requires significantly lower converter performance levels and only a 25,000 mile durability requirement. If EPA were to set performance and durability standards for aftermarket converters in-line with California's requirements, hundreds of tons per day of hydrocarbon and NOx emissions could be eliminated from the existing fleet of U.S. gasoline cars, minivans, SUVs, and light-duty trucks.

## 7.0 SUMMARY

Looking ahead, transportation GHG emissions are forecast to continue increasing rapidly, reflecting the anticipated impact of factors such as economic growth, increased movement of freight by trucks and aircraft, and continued growth in personal travel. The transportation sector is the largest source of domestic $CO_2$ emissions, producing 33% of the nation's total in 2006. There are significant opportunities to reduce greenhouse gas emissions from the transportation sector through the design of fuel efficient powertrains that include advanced exhaust emission controls for meeting even the most stringent criteria pollutant standards. MECA believes that advanced emission control systems have a critically important role in future policies that aim to reduce mobile source greenhouse gas emissions. These emission control technologies allow all high efficiency powertrains to compete in the marketplace by enabling these powertrains to meet current and future criteria pollutant standards. In nearly all cases, these fuel-efficient powertrain designs, combined with appropriate emission controls, can be optimized to either minimize fuel consumption impacts associated with the emission control technology, or, in some cases, improve overall fuel consumption of the vehicle. This optimization extends beyond carbon dioxide emissions to include other significant greenhouse gases such as methane and nitrous oxide. In the case of gasoline vehicles, additional climate change benefits could be obtained by lowering gasoline fuel sulfur levels to enable the use of lean NOx adsorber catalysts on gasoline lean-burn engines.

Diesel particulate filters are particularly effective at removing black carbon emissions from diesel engines and effective climate change policies should include programs aimed at reducing black carbon emissions from existing diesel engines through effective retrofit programs that implement filters on the full range of in-use diesel engines operating in the U.S. Ground level ozone also has a strong linkage to climate change. EPA needs to continue its efforts to review and adjust criteria pollutant programs for all mobile sources going forward to not only provide needed health benefits from technology-forcing emission standards but also the important co-benefits these emission standards have on climate change.