

Aftermarket Converter Technology for Gasoline Light-Duty Vehicles



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1.0 Executive Summary

The catalytic converter is the essential component of a light-duty vehicle's emission control system. In the U.S., new catalytic converters have been installed on passenger cars and light-duty trucks since 1975 to help the vehicles meet federal or California light-duty vehicle emission standards. Original equipment (OE) catalytic converters are designed to last the life of properly tuned and maintained vehicles. For model year 1998 and newer vehicles, this represents 120,000 miles (for some California-certified PZEV vehicles, the useful life is 150,000 miles).

Due to high durability requirements necessary to last the full useful life of a vehicle, the OE catalysts must use high levels of precious metals and other expensive materials. Over time, however, the emission reduction effectiveness of an OE catalytic converter may be severely degraded or even completely destroyed. Excessive vibration or shock, excessive heat, lack of proper vehicle maintenance, or improper vehicle operation each can cause catalyst failures. In addition, converters can be structurally damaged in vehicle accidents or if the vehicle hits an obstruction such as a large rock or debris on the road. Converters can also be removed intentionally by vehicle owners – an illegal practice – to try to improve vehicle performance or fuel economy. If the vehicle is out of warranty, the price of a new OE converter can be cost prohibitive. Compounding the problem, many vehicles requiring a replacement converter have considerably less than 100,000 miles of expected life remaining, making the cost of a new OE converter difficult to justify. Because of this and the sometimes scarce availability of the original equipment converters, less expensive aftermarket converters give vehicle owners more incentive to replace their worn-out or damaged converters.

There are several options available to consumers. The most cost-effective replacement converters are newly manufactured converters. These devices are manufactured by many of the same companies supplying OE converters. Due to the lower durability requirements (25,000 to 50,000 miles in California), manufacturers are able to use lower amounts of precious metals and other materials to offer substantial cost savings to the consumer. Another type of replacement converter offered in states other than California are known as remanufactured, or used, converters. These converters are removed from vehicles in junk yards and resold. Although they must meet minimum emission standards at the time of sale, they do not have any durability requirements and, therefore, there is no way to know how long they will continue to function or what level of emission reduction will be realized.

Countries with established motor vehicle emission control programs where catalytic converters have been utilized have recognized the need for aftermarket converters to maintain the effectiveness of these programs. In the U.S., a federal aftermarket converter program has been in place since 1986 (California began their program in 1988) and it has resulted in the replacement of over 50 million converters that were damaged, destroyed, or removed. As a result, millions of tons of harmful pollutants that would have otherwise been emitted were cleaned up by aftermarket converters. Since the effectiveness of aftermarket converters depends on their durability,

performance, and proper application, both the federal and California programs have required aftermarket converters to meet certain minimum performance standards while also requiring installers to install only converters approved for specific vehicles. Both of these aftermarket converter programs also contain warranty, reporting, and recordkeeping requirements, which make it possible for governments to enforce the requirements and ensure that vehicle owners get what they pay for. Any state agency wishing to receive the full benefit of their converter replacement program must also implement a vehicle inspection and maintenance (I/M) program to periodically ensure the converters installed on the vehicles are functioning properly and delivering the emission benefits.

An effective aftermarket converter program for gasoline-powered, light-duty vehicles is an important element of any country's comprehensive motor vehicle emission control program. Without an effective program, two unacceptable results will likely occur. First, many vehicles with damaged or missing converters will not be repaired and will continue to emit high levels of pollution. Second, inferior replacement converters, which will provide little or no pollution reduction benefit, will start to be sold in the marketplace. The consequences of these events can hamper efforts of air quality officials and others to reduce pollution from automobiles, and cause the general public to lose confidence in motor vehicle emission control programs and emission control technology.

2.0 Catalytic Converter Technology

Catalytic converters reduce vehicle exhaust emission levels by chemically converting engine-out emissions before the exhaust gas leaves the tailpipe. A converter contains a substrate housed in a stainless steel canister that directs exhaust gases through narrow channels. A porous catalyst layer is applied to the interior surface of the channels and facilitates the conversion of pollutants into primarily water vapor, carbon dioxide, and nitrogen. Within this layer are small sites of catalytic metal – platinum (Pt), rhodium (Rh), and/or palladium (Pd) – which catalyze the desired reactions. This technology is commonly referred to as a three-way catalyst (TWC) due to the three simultaneous reactions occurring over the catalyst. These include two oxidation reactions to reduce hydrocarbons (HC) and carbon monoxide (CO) and a reduction reaction involving NO_x with CO over a suitable catalyst to reduce oxides of nitrogen to nitrogen gas and carbon dioxide. The TWC has been the core technology used to clean-up emissions from gasoline spark-ignited engines since the early 1980s. There are no moving parts, just large areas of interior surfaces coated with catalytic metals within the honeycomb structure. The exact combination of these precious metals differs according to the level of engine-out emissions and the required emission reductions. Current catalytic converter designs are more than 95% efficient in removing HCs and CO, and at least 85% effective at reducing NO_x over the lifetime of the converter.

2.1 Oxidation Catalytic Converter (Two-Way Converter)

The first type of converter introduced on gasoline vehicles in the U.S. in the 1970s was the oxidation converter, which was designed to oxidize only HCs and CO. It

is called an oxidation catalytic converter because the transformation of harmful pollutants into harmless gases is accomplished by oxidation. The substrate surfaces inside the converter are covered with a thin porous catalytic layer that contains a combination of precious metals particularly active for oxidation. The HC and CO entering the converter react with oxygen (O_2) molecules from the air to form carbon dioxide (CO_2) and water vapor.

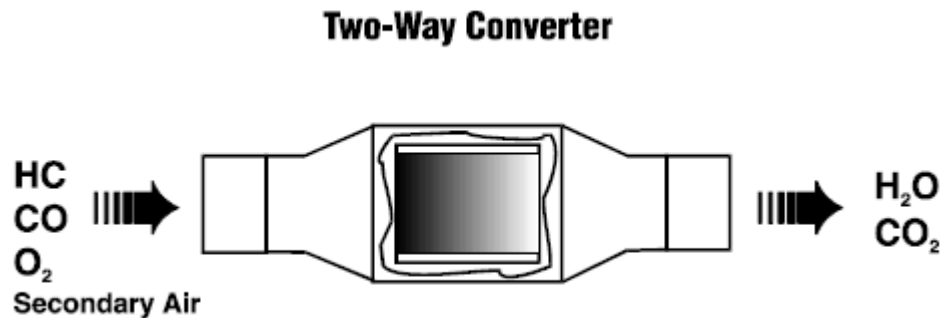


Figure 1. Diagram of a two-way catalytic converter.

Although these converters are no longer used on gasoline vehicles, they serve as the basis for catalyst technology on most diesel-powered engines due to the high concentration of oxygen in their exhaust. Diesel oxidation catalysts (DOCs) have been installed on new light-duty diesel vehicles since 1994. On 2007 and newer light-duty and heavy-duty diesel vehicles requiring control of particulate matter (PM) and NO_x emissions, the DOC continues to be an integral component of the exhaust control system. (For more information on control of emissions from diesel vehicles, see the MECA white papers entitled “Emission Control Technologies for Diesel-Powered Vehicles” and “Retrofitting Emission Controls on Diesel-Powered Vehicles” at: www.meca.org/resources/reports.)

2.2 Three-Way Catalytic Converter

The three-way catalytic converter (TWC) has been the primary emission control technology on light-duty gasoline vehicles since the early 1980s. The use of TWCs, in conjunction with an oxygen sensor-based, closed-loop fuel delivery system, allows for simultaneous conversion of the three criteria pollutants – HCs, CO, and NO_x – produced during the combustion process of an internal combustion, spark-ignited engine. The conversion of these three pollutants is maximized by controlling operation of the gasoline-fueled engine near the stoichiometric air/fuel (A/F) condition through the use of the oxygen sensor control loop. Some converters have a three-way and an oxidation catalyst together in one housing and are called three-way-plus-oxidation converters or dual-bed converters. These converters have air injected between the two sections to help the two different chemical reactions occur.

Figures 2 and 3 depict a cut-away drawing and a cut-away photo of typical three-way catalytic converters, one with a ceramic substrate and one with a metallic substrate. The active catalytic materials are present as a thin coating of precious metals (e.g., Pt, Pd, Rh) and oxide-based inorganic promoters and support materials on the internal walls of the honeycomb substrate. The substrate typically provides a large number of parallel flow channels to allow for sufficient contacting area between the exhaust gas and the active catalytic materials without creating power losses due to back pressure.

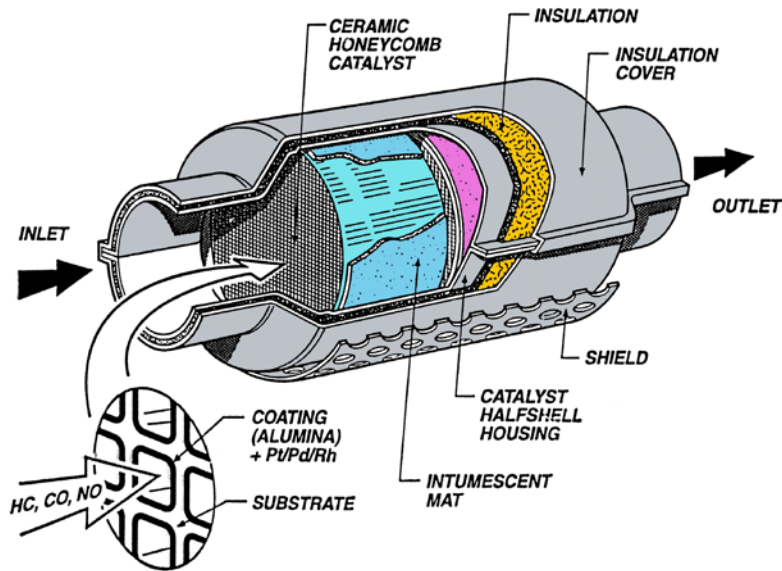


Figure 2. Three-way catalytic converter with ceramic substrate.

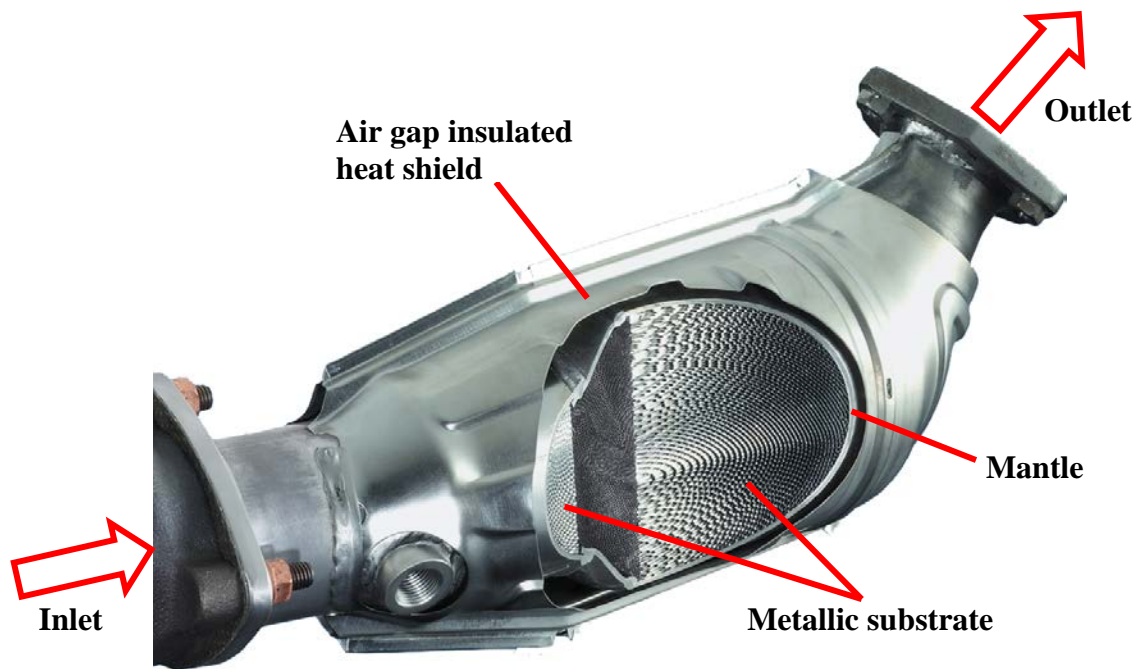


Figure 3. Three-way catalytic converter with metallic substrate.

Catalytic materials are typically applied by contacting the substrate with a water-based slurry containing the active inorganic catalyst materials. The coated substrate is contained within an outer metal-based shell that facilitates connection of the converter to the vehicle's exhaust system through flanges or welds. For ceramic honeycomb-based substrates, cordierite, a magnesium aluminosilicate compound, is the preferred ceramic substrate material due to its low coefficient of thermal expansion, good mechanical strength characteristics, and good coating adhesion properties. The ceramic substrate is formed as a single body using an extrusion process followed by high-temperature firing. Metal-foil based substrates are made from thin ferritic-based specialty stainless steel foils brazed together to form the parallel flow passages. The ferritic foil alloy provides good oxidation resistance in the exhaust environment, good mechanical strength, and an oxidized surface that promotes good adhesion of the catalytic coating to the foil.

In the case of ceramic substrates, a special oxide fiber-based mounting material is used between the substrate and the metal outer shell to hold the substrate in place, provide thermal insulation, and cushion the ceramic body against the shell. The outer metal shell, or mantle, is an integral part of the metal substrate production scheme and no additional mounting materials are generally required. As shown in Figures 2 and 3, in some cases the converter housing, or "can," can be surrounded by a second metal shell with an annular gap between them. This type of arrangement provides additional heat insulation to the converter. The annular region between the two shells may be left as an

air gap or filled with a “support mat” insulation material (such as an inorganic fiber-based material).

Support mats provide much of the physical durability of the converter. Mat support material provides durability to the device by acting as a shock absorber for the ceramic substrate, retaining the substrate in place during operation, providing insulation to keep the outer shell cool, acting as a gas seal, allowing for manufacturer tolerance, and compensating for expansion of components.

2.3 Improvements in Catalytic Converter Technology

Although the primary function of a three-way catalytic converter has remained relatively constant during its nearly thirty years of use on light-duty gasoline vehicles, each of the primary converter components (catalytic coating, substrate, mounting materials) has gone through a continuous evolution and redesign process aimed at improving the overall performance of the converter while maintaining a competitive cost-effectiveness of the complete assembly. These catalytic converter advances include improvements in catalytic converter washcoats, precious metal loading, and substrate designs, in combination with better vehicle fuel control systems.

A similar re-engineering effort has occurred with other exhaust system components, such as exhaust manifolds and exhaust pipes, which complements improvements in catalytic converter technology. The focus of these manifold and other exhaust component improvements has been on exhaust system thermal management and heat conservation through the use of low thermal mass, air gap-insulated components.

A large driver in the continuous improvement processes for both catalytic converters and exhaust system components has been the adoption of increasingly tighter emission standards and durability requirements for new light-duty vehicles required by the federal Tier 2 and California’s LEV II regulations. The performance-based catalytic converter re-engineering effort has had three main focuses: wide application of close-coupled converters mounted near the exhaust manifold of engines, the development and use of high cell density substrates, and the design of advanced, high performance TWCs for both close-coupled and underfloor converter applications.

Manufacturers have gained a greater understanding of the interaction of the precious metal catalysts and the oxide support materials used in the washcoat. The use of more thermally stable support materials and mixed oxides exhibiting important functionalities like oxygen storage has led to a new level of performance from these catalysts. Significant advances have occurred in the manufacturing and coating of the substrate to facilitate positioning the precious metals at different locations along the length of the channel and on specific support materials within the layer to either promote specific reactions or protect the precious metal from poisons in the exhaust. Further advances have been in catalyst coating practices, such as zone coating technology, to strategically locate precious metal functionality along the length of a channel, leading to further innovations in converter architecture. These advances combine to produce

catalysts that can survive high temperature exposure and deliver higher levels of performance over a longer useful life. Due to stricter regulatory requirements, new vehicles and aftermarket converters sold in California have most benefited from these technological advances (see Section 4.0).

Another significant advancement that occurred in the 1990s was the implementation of on-board diagnostic (OBD II) systems on new light- and medium-duty vehicles (starting with the 1996 model year). These systems use sensors, such as oxygen sensors in the exhaust, and a vehicle's on-board computer to monitor the performance of its emission control systems, including the catalytic converter. This has given regulators a way to ensure that the emission control system and catalyst are functioning properly over the full useful life of a vehicle. To ensure that catalysts are compatible with the OBD II system and do not cause the vehicle's malfunction indicator lamp (MIL) to illuminate when the catalyst is functioning properly, manufacturers have implemented tight quality control procedures in their processes. Beginning in 2009 in California, these new materials and coating technologies have been applied to advanced OBD II-compliant aftermarket converters, as well as more durable aftermarket converters for older, pre-OBD vehicles, to achieve significant reductions of HC and NO_x emissions from the existing passenger fleet. (For more information on advanced catalysts for light-duty vehicles, see MECA's white paper entitled "Tier 2/LEV II Emission Control Technologies for Light-Duty Gasoline Vehicles" at: www.meca.org/galleries/default-file/Tier%202%20white%20paper%20June%202007.pdf.)

3.0 U.S. Environmental Protection Agency's Aftermarket Converter Program

About 10 years after catalytic converters were first introduced in the U.S., EPA officials determined that a replacement catalytic converter program was needed. The owners of vehicles with damaged or missing converters generally were unwilling to pay the high costs of purchasing a converter equivalent to the vehicle's original converter. EPA estimated that the cost of purchasing a new OEM converter could range from \$300 to \$1,000. Also, vehicle owners were often unable to locate OE converter replacements at the retail level or the consumer had to wait weeks for the part to be ordered and delivered. Compounding the problem, many vehicles requiring a replacement converter had considerably less than 100,000 miles of expected life remaining, making such large repair costs difficult to justify. A market for aftermarket converters began to develop, but some of these aftermarket converters were inferior products, offering little or no pollution control capability. Without regulatory requirements, there was no way to determine whether these converters were performing properly or if they were installed on the right vehicles. In response, EPA established an aftermarket converter enforcement policy.

The U.S. EPA's current interim aftermarket converter enforcement policy, entitled "Sale and Use of Aftermarket Catalytic Converters," went into effect on August 5, 1986. After December 18, 1986, new and remanufactured (used) aftermarket converters were required to meet the standards imposed by EPA. During this time, existing inventory of older converters could be sold; however, after January 1, 1988, only new or

used converters meeting the requirements could be sold and installed. Under the federal program, remanufactured or used converters can be sold as aftermarket replacement converters. These converters are removed from vehicles in junk yards and resold. Although used converters must meet minimum emission standards at the time of sale, they do not have any durability requirements and, therefore, cannot ensure a level of emission reduction over any known period of operation. EPA's aftermarket converter policy also requires installers to maintain certain records pertaining to the aftermarket converters they install.

EPA administers the federal aftermarket converter program. The program is based on a performance-based requirement stated in terms of the catalytic converter's pollution control efficiencies. EPA allows the same aftermarket converters to be sold for use on a wide variety of makes and models, provided that the converter manufacturer has demonstrated that the performance standards can be met for all of the vehicles to which the converter is offered for sale. This demonstration is made by testing the converter on a vehicle in which meeting the emission control requirements would be the most difficult (called the "worst case" vehicle).

Since issuing its interim enforcement policy, the U.S. EPA has thus far decided not to issue actual regulations specific to aftermarket catalytic converters and has not announced any plans to do so in the future.

3.1 Performance Requirements of EPA's Aftermarket Converter Policy

The U.S. EPA aftermarket converter program requires that a catalytic converter demonstrate specific conversion efficiencies over 25,000 miles of operation or five years. The emission reductions at the end of this durability period must be at least 70% for HCs, 70% for CO, and 30% for NOx. To demonstrate compliance, the converter manufacturer must conduct vehicle mileage accumulation and emission testing on actual production converters. The vehicles for which the converter is an appropriate installation are proposed by the converter manufacturer. If a manufacturer intends to make the replacement converter available for more than one make or model of vehicle, it must test its prototype on the vehicle representing the "worst case" for the application covered as defined by the agency based on the highest test weight and largest engine displacement within the application category. The EPA program requires that the manufacturer demonstrate, by testing over a specified testing protocol (i.e., the EPA Federal Test Procedure with a chassis dynamometer), that the emission performance requirements can be met after 25,000 miles of vehicle aging. To achieve this level of durability, the vehicle must be driven over a prescribed route until the accumulated mileage has been achieved.

Following this aging protocol, the manufacturer must demonstrate that the converter still meets the above emission limits. Once a converter has met the applicable testing and performance requirements, the converter manufacturer is required to provide EPA with documentation prior to introducing the product for sale. The type of information EPA requires includes a summary of the test results, including the vehicles

tested, method of mileage accumulation, name and location of the testing facilities, the intended vehicle application list, and a detailed description of the qualified converter in all material respects. EPA reserves the right to conduct confirmatory testing of any replacement converter offered for sale in the U.S. Failure to successfully pass the confirmatory testing can result in an EPA order to cease sale of the product.

3.2 Installation and Recordkeeping Requirements

EPA established installation and recordkeeping requirements for the installer to ensure that converters are installed only under the specified conditions and that the replacement converter has been approved for the vehicle.

Replacement converters that meet the performance requirements described above may only be installed in the following situations to comply with federal anti-tampering provisions:

- 1) the vehicle is missing a converter,
- 2) a state or local inspection program has determined that the existing converter has been poisoned, damaged, or otherwise needs replacement, or
- 3) the vehicle is beyond the applicable vehicle warranty.

The second situation normally would include only plugged converters or those damaged to the point where unreparable exhaust leaks are present. Documentation of the need for replacement must be made and maintained by the installer for a specified period.

3.3 Warranties

The converter manufacturer must warrant that the converter will meet the applicable emission control efficiencies for 25,000 miles, that the external converter shell, including the end pipes, will last for five years or 50,000 miles (whichever occurs first), and that the converter will not constitute a safety hazard. EPA requires that manufacturers enclose in the packaging for each converter the specific vehicle applications of that converter and a warranty application card to be returned to the converter manufacturers. Converter manufacturers are required to retain the warranty cards and submit reports to EPA twice a year.

4.0 California's Aftermarket Converter Program

In 1988, the California Air Resources Board (ARB) adopted its own regulations that permit the sale and installation of non-OEM replacement catalytic converters on California vehicles. The requirements specified minimum conversion efficiencies for aftermarket converters through 25,000 miles of use. The conversion efficiencies of 70% for HC and CO and 60% for NO_x over the full useful life of the converter were chosen primarily to provide some consistency with the EPA program while offering emission

reductions beyond the federal converter replacement policies. The NO_x efficiency requirement was adjusted upward from the 30% federal specification because of the need for greater NO_x reductions in California. ARB testing at the time indicated that 60% NO_x conversion efficiency was reasonable compared to the performance of higher mileage – but properly maintained – original equipment converters used on vehicles with emission control technologies of the late 1980s.

As discussed previously, the emission requirements for new light- and medium-duty vehicles have increased dramatically under California's LEV II requirements and federally through EPA's Tier 2 requirements. OE catalyst performance has correspondingly increased substantially due to improved catalyst formulations and substrate designs that provide for higher efficiencies and faster warm-up times (see Section 2.3). Furthermore, the incorporation of OBD II technology starting with the 1996 model year vehicles made it necessary for aftermarket converters to be compatible with the OBD system. To accommodate this requirement, converter manufacturers signed a memorandum of understanding (MOU) in 2001 with ARB to sell only OBD II-compatible converters in California. These converters could not cause a MIL illumination when installed on an OBD II-equipped vehicle and could not be installed on vehicles less than eight-years old or having 80,000 accumulated miles, unless the converter was missing. Under this MOU, OBD II-compatible converters carried a five-year, 50,000-mile warranty, while pre-OBD aftermarket converters maintained a 25,000-mile warranty. Although pre-OBD aftermarket converters continued to meet the 70%/70%/60% reduction criteria for HC/CO/NO_x, respectively, OBD II-compatible converters could not exceed the applicable new vehicle exhaust emission certification standards over the full useful life.

In 2007, ARB decided to revise their aftermarket converter requirements to ensure that the in-use emission performance of OBD II vehicles equipped with aftermarket converters would not be adversely compromised by the use of non-OE replacement catalysts, as well as to extend the emission benefits of OBD II-compliant converters to older, pre-OBD vehicles. This meant that the aftermarket converters had to be fully OBD II-compliant and function just like the OEM converter but with somewhat lower durability requirements. A number of other requirements were incorporated in these amendments to California's aftermarket converter regulation. As part of their cost-benefit analysis, the state was able to demonstrate the significant HC+NO_x emission reductions that their upgraded program could achieve. This amended regulation made up a portion of the state's proposed ozone and PM_{2.5} SIP commitments for 2014.

4.1 Requirements of California's Aftermarket Converter Program

California's latest amendments to their aftermarket converter program were adopted by the ARB Board on October 25, 2007, and went into effect on July 1, 2008, by prohibiting the sale of used or remanufactured replacement converters after this date. This was an essential component that allowed California to meet their emission goals by ensuring that all replacement converters meet the full useful life emission requirements

for five years and 50,000 miles. New aftermarket converter performance requirements went into effect on January 1, 2009.

The primary components of the new regulation include:

- 1) Set mass-based performance standards based on vehicle certification tailpipe emission levels for all aftermarket converters sold in California.
- 2) Requires a five-year, 50,000-mile warranty for all aftermarket converters.
- 3) Allows for the use of accelerated aging of converters using a RAT-A engine dynamometer cycle rather than actual on-vehicle mileage accumulation for durability demonstration (RAT-A refers to a defined engine dynamometer-based converter aging cycle).
- 4) Requires demonstration of full OBD II-system functionality without exceeding 2.6 times the threshold emission limit.
- 5) Requires catalyst or converter manufacturers to submit quarterly product quality reports to ensure consistent catalyst loading.

To facilitate as broad a coverage as possible for certification of pre-OBD converters, ARB selected worst case vehicles within four general classifications. These include passenger cars (PC-1 and PC-2) and light-duty trucks (T-1 and T-2) with single and dual exhaust systems. For OBD II converter certification, manufacturers must propose a list of vehicles for each new aftermarket converter. ARB selects representative vehicles from the list for the manufacturer's compliance determination. Emission compliance is conducted on RAT-A aged converters and oxygen sensors. Both pre-OBD and OBD II-compliant aged converters must meet the mass-based (g/mile) new vehicle certification limits for the vehicle being tested.

To demonstrate full functionality and compliance with the vehicle OBD II system, the catalyst must be subjected to a much more aggressive set of durability aging conditions. This may include an engine misfire-type of aging, a high temperature oven aging, or some other aging protocol approved by ARB. Subsequent to this aging, manufacturers must demonstrate that during emission testing the converter will cause the OBD II-system MIL light to illuminate while at the same time not exceed the emission limit by more than 1.5 times the OBD threshold limit required of the OEM (1.75 times the tailpipe certification limit). This equates to 2.6 times the certification emission limit for aftermarket converters under California's regulation. The higher threshold limit for aftermarket converters provides some limited flexibility for converter manufacturers to certify to broader vehicle families.

The amendments require manufacturers to monitor their production process to ensure that production parts actually meet the specifications upon which ARB approval is based. Manufacturers must check for adequate precious metal content, base metal content, and washcoat loading. Inspections to ensure proper application of the washcoat, installation of matting materials, and the absence of leaks in the converters shell are also required. Manufacturers must demonstrate compliance with this requirement through quarterly reports to ARB.

California has an extensive vehicle I/M program (Smog Check) which is a critical component of enforcing their regulation. Regular enforcement is part of the Smog Check program. Prior to conducting emission tests or downloading OBD information from the computer, technicians are required to check the device label and make sure that the proper, certified aftermarket converter is installed on the vehicle.

The regulation requires installers to:

- 1) ensure that each aftermarket converter has been approved by ARB for installation on the vehicle model in question,
- 2) verify that each vehicle needing a new aftermarket catalytic converter is outside of the vehicle manufacturer's warranty period for the original equipment converter (typically, seven years or 70,000 miles),
- 3) establish a legitimate need for an aftermarket converter by first examining the existing converter and exhaust system, and
- 4) install the aftermarket converter in the same location as the original equipment converter on a one-for-one basis, and without relocating or removing other converters or exhaust oxygen sensors.

Further enforcement is conducted randomly by ARB enforcement officers of the installer's inventories and service records.

4.2 Air Quality Benefits of California's Aftermarket Converter Program

The benefit of applying advanced OBD II-compatible converters on non-OBD vehicles is evident from test results obtained by ARB in 2006 and discussed in their Staff Report supporting their October 2007 revised procedures for new aftermarket catalytic converters. Agency staff recruited fourteen pre-OBD test vehicles that averaged 140,000 to 160,000 odometer miles and that passed the Smog Check to eliminate any that may have had emission-related problems. Five of the vehicles were fitted with aftermarket catalysts that met the pre-2009 standards for non-OBD II vehicles of 70%/70%/60% HC, CO, and NO_x reduction, respectively. The remaining nine pre-OBD vehicles were fitted with aftermarket converters manufactured to the current California requirements. After approximately 8,000 miles of mileage accumulation, the advanced catalysts resulted in 50-75% lower emissions of all three criteria pollutants compared to the older aftermarket catalyst technology (see Table 1). Furthermore, the advanced catalysts demonstrated far better durability, resulting in 60% less deterioration in HC emissions and 75% less deterioration in NO_x emissions after mileage accumulation relative to older aftermarket converters.

Table 1. Emission results comparing old and current aftermarket converter technology in California.

Test Vehicles with AM Converter Technology Meeting:	Accumulated Mileage	Emission Levels (g/mile)		
		HC	CO	NO _x
Old Requirements	8,754	0.605	4.987	1.431
Current Requirements	7,847	0.253	2.227	0.358
Difference	908	0.352	2.760	1.073

ARB conducted additional emission tests on OBD II vehicles equipped with the previous first generation aftermarket converters and the current OBD II aftermarket converters and observed a significant emission reduction on fresh as well as moderately aged (approximately 8,000 miles) converters. The data for a 1997 Chevrolet Astro van equipped with a 4.3 L engine is shown in Figure 4. ARB observed that the OBD II-compliant aftermarket converters provided the same emission benefits as OEM catalysts at a fraction of the cost.

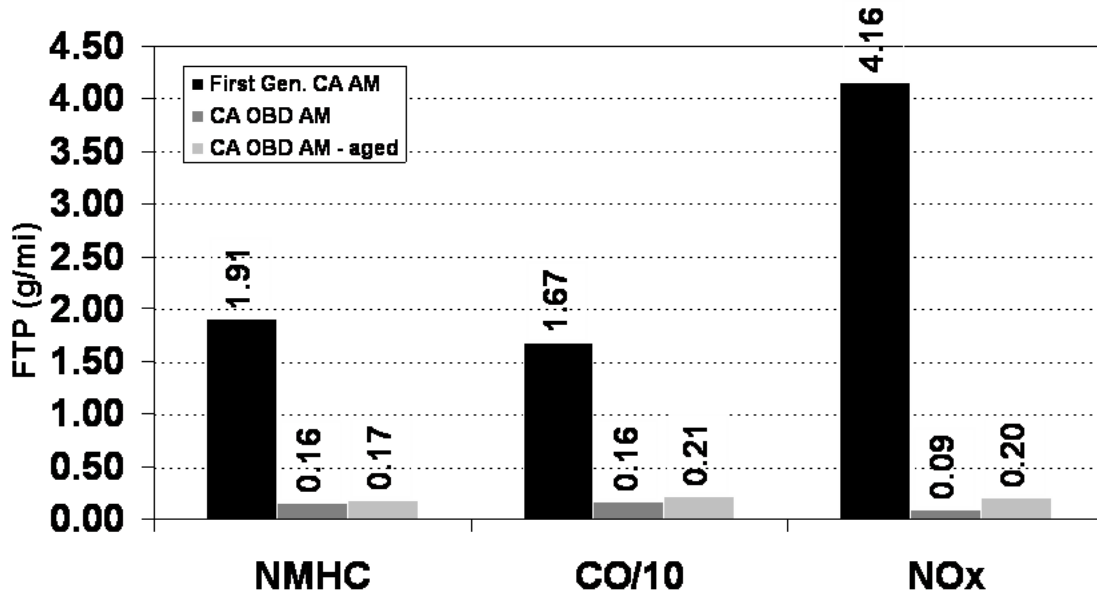


Figure 4. ARB emission test results of old and new aftermarket catalyst technology on a 1997 4.3 L Chevrolet Astro van.

To estimate the emission benefit of the new regulation, California relied on sales receipts that showed that, in 2006, 880,000 vehicles had their converters replaced and 74% were on pre-OBD II vehicles. Because the newer OBD II converters were already required to be installed on OBD-equipped vehicles since 2001 under an MOU (see Section 3.1), ARB relied on only the incremental benefit from the pre-OBD II fleet to

estimate the emission benefit of the regulation. The vehicle population data and emission benefits were analyzed using California’s Emission Factors (EMFAC) model to predict the emission inventory in 2012 with and without the newly adopted regulation. The results showed a significant benefit from using the advanced aftermarket converter technology on pre-OBD II vehicles. ARB estimated that by the year 2012 all existing aftermarket converters would have been replaced with the new OBD II-compliant converters resulting in an estimated emissions benefit of 5.3 tons/day of HCs removed and 31.3 tons/day of NOx. They estimated that this would affect 1.26 million pre-1996 model year vehicles.

As part of their regulatory impact analysis, ARB estimated that the cost impact of the new aftermarket converter technology would be approximately \$200 above the cost of existing first generation aftermarket converters. While this price increases may seem high, the new aftermarket converter designs provide better, more durable performance lasting twice as long (50,000 miles versus 25,000 miles). And, in the end, costs would actually remain reasonably consistent with historical values because consumers would be less likely to need to purchase a second or third replacement catalyst during a vehicle’s lifetime. According to the ARB analysis, the \$200 net increase over the \$60-\$150 cost of the older pre-OBD aftermarket converters in California represents a substantial savings over OEM replacement converters costing in the range of \$327-\$1,089.

A second study conducted by ARB involving 21 pre-OBD vehicles showed that, after 6,000-9,000 accumulated miles, the vehicles fitted with OBD II-compliant converters delivered the same emission benefit as those fitted with OE replacement converters and both performed twice as well as the previous generation California aftermarket converters (see Figure 5). The selected vehicles consisted of pre-OBD emissions technology meeting pre-Tier 1 emission standards. The vehicles were required to pass California’s Smog Check prior to installation of the new aftermarket converters.

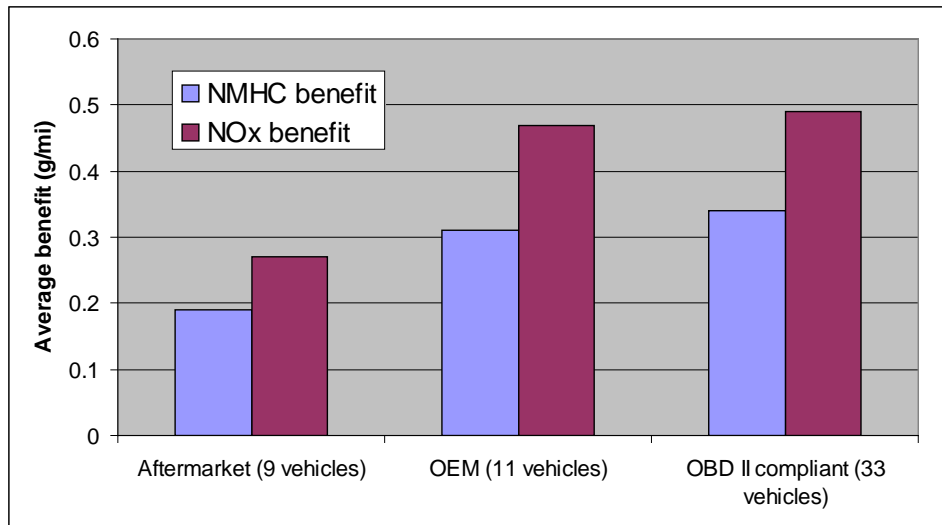


Figure 5. Replacement converter emission benefit on 1981-1992 MY vehicles.

5.0 MECA Test Program Comparing California and Federal Aftermarket Converters

To evaluate the difference in emission performance between state-of-the-art ARB aftermarket converters and those offered in the federal market, MECA member companies who manufacture aftermarket converters conducted a test program in 2012 to compare the two technologies across five California LEV I-certified vehicles (three passenger cars, an SUV, and a light-duty pick-up truck). The five test vehicles were: a 1999 Volkswagen Jetta (four cylinder, 2.0 L, single exhaust configuration), a 2000 Chevrolet Camaro (six cylinder, 3.8 L, single exhaust configuration), a 1999 Mercury Grand Marquis (eight cylinder, 4.6 L, dual exhaust configuration), a 2002 Ford F-150 (eight cylinder, 5.4 L, dual exhaust configuration), and a 1999 Dodge Durango (eight cylinder, 5.9 L, single exhaust configuration). These five test vehicles were selected to represent the most common engine and exhaust configurations in the U.S. light-duty fleet.

Commercial aftermarket converters designed to meet federal and ARB emission requirements were aged out to 25,000- and 50,000-equivalent miles using engine dynamometer aging on the RAT-A cycle. The aged converters were installed on the vehicles and tested for their weighted emissions of total hydrocarbons (THC), non-methane hydrocarbons (NMHC), carbon monoxide (CO), and oxides of nitrogen (NO_x) over the FTP-75 cycle.

Figures 6-9 show the emission levels for the three passenger vehicles tested.

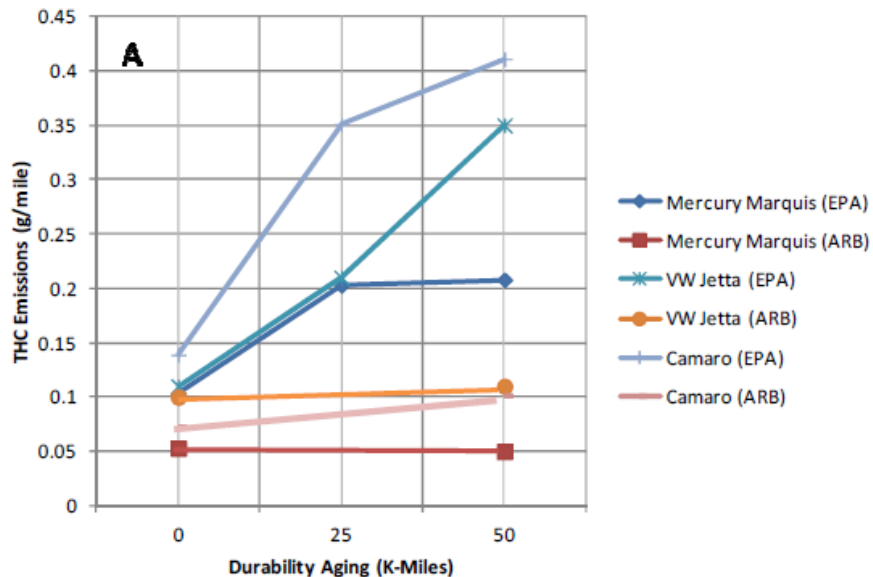


Figure 6. Emissions of total hydrocarbons (THC) in weighted g/mile for the three passenger vehicles.

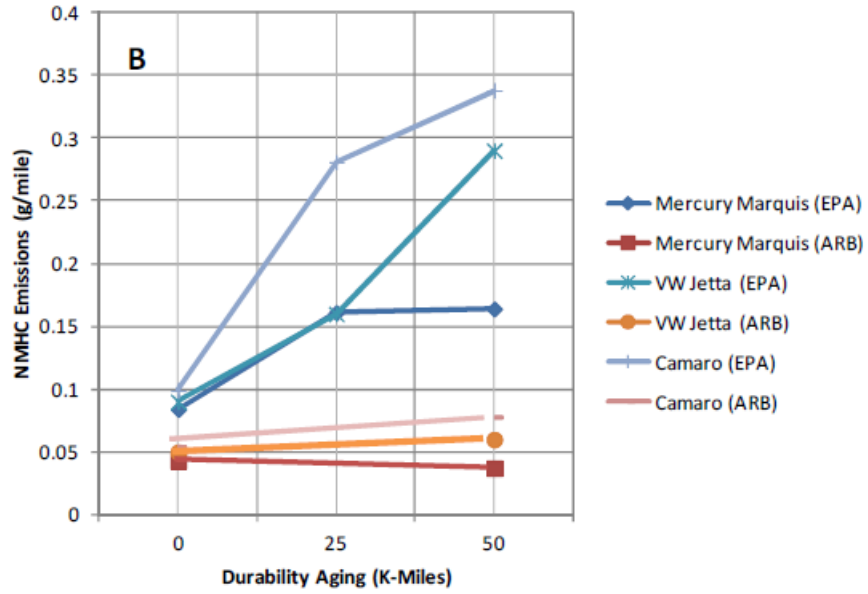


Figure 7. Emissions of non-methane hydrocarbons (NMHC) in weighted g/mile for the three passenger vehicles.

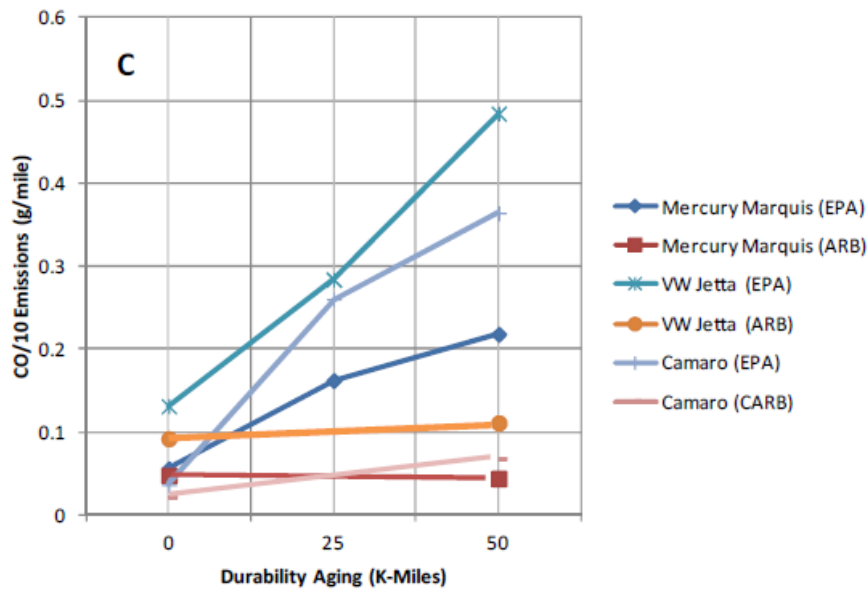


Figure 8. Emissions of carbon monoxide (CO) (divided by 10) in weighted g/mile for the three passenger vehicles.

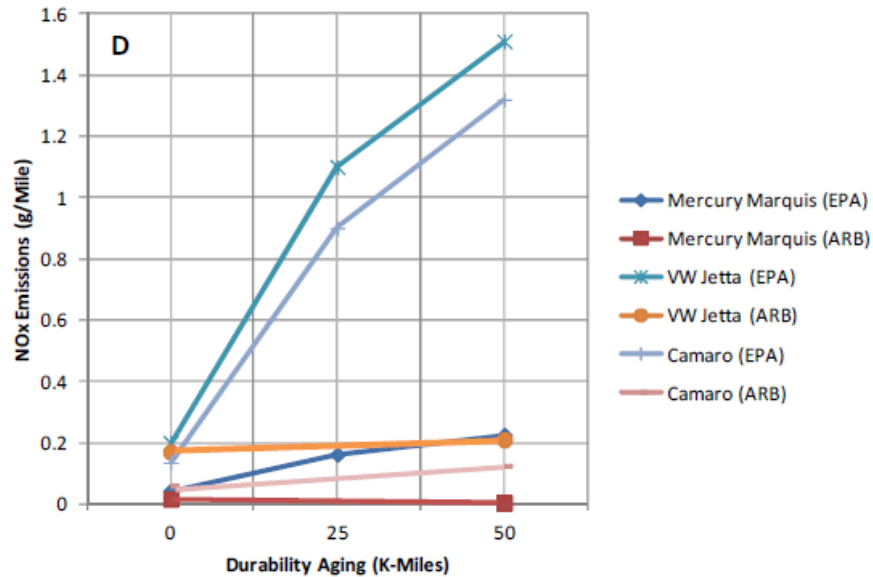


Figure 9. Emissions of oxides of nitrogen (NOx) in weighted g/mile for the three passenger vehicles.

The passenger car data show a significant difference between the deterioration rates of the federal converters and the California-certified converter technology for all three vehicles. All three ARB converters exhibit an emission benefit of at least 50% to 75% for THC and CO and a much higher advantage of 90-94% additional NOx reductions at the mid-level aging point over the federal catalysts. These differences in emissions increase to 70-80% for HC and CO and 85-98% for NOx after 50,000 miles of aging. The deterioration of THC emissions for the federal converter was most significant on the Jetta as the slope increases beyond the 25,000-mile point. The magnitude of the NOx emission level was the highest for the Jetta and Camaro equipped with federal converters with approximately 1 g/mile of NOx being emitted after FUL aging (equivalent to 25,000 miles). An average of the three passenger car converters reveals an emission reduction advantage of 67% THC, 73% CO, and 89% NOx when using the ARB-approved converters after the EPA FUL aging of 25,000 miles. The benefit of the ARB-approved converters increased to 76% HC, 79% CO, and 92% additional NOx conversion after the full ARB aging of 50,000 miles.

A comparable data set for the two light-duty truck models is plotted in Figures 10-13.

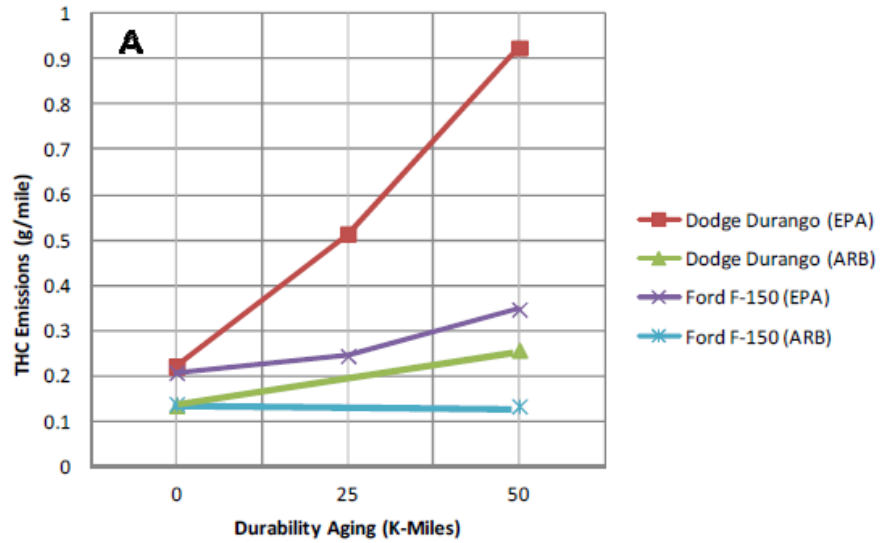


Figure 10. Emissions of total hydrocarbons (THC) in weighted g/mile for the SUV and the light-duty pick-up truck.

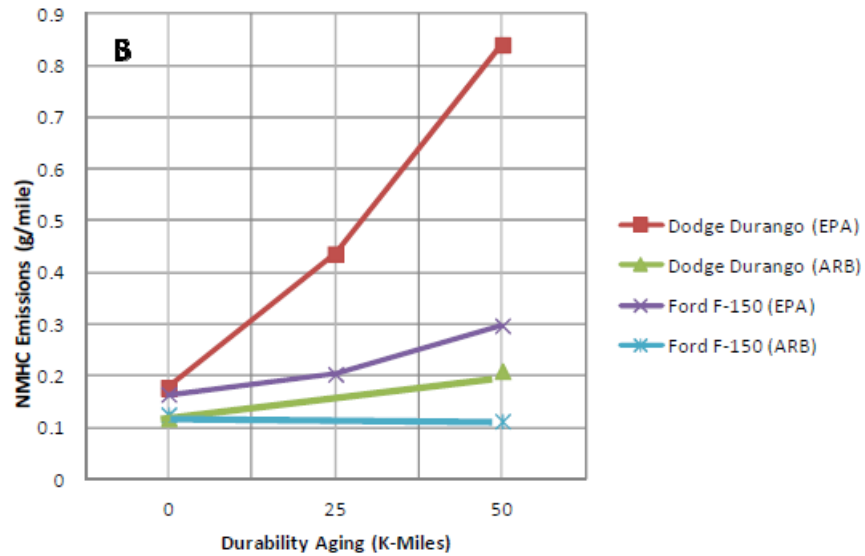


Figure 11. Emissions of non-methane hydrocarbons (NMHC) in weighted g/mile for the SUV and the light-duty pick-up truck.

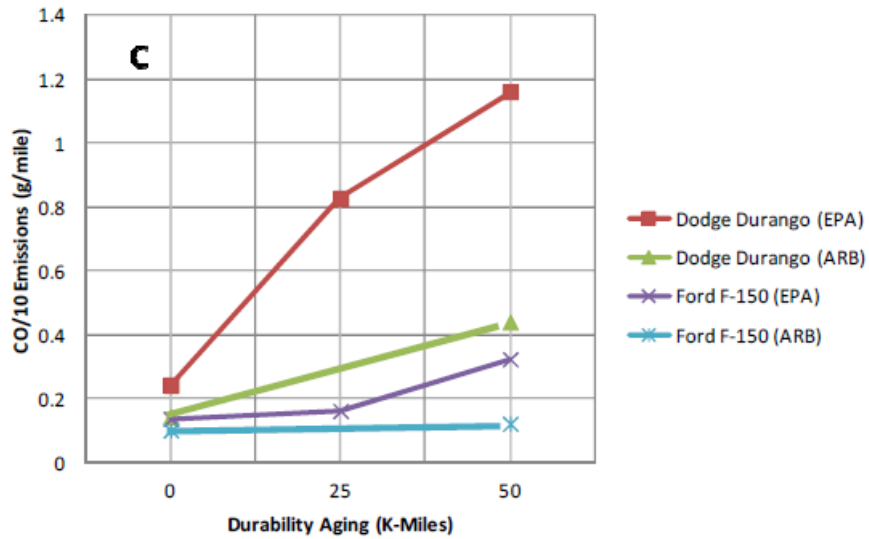


Figure 12. Emissions of carbon monoxide (CO) (divided by 10) in weighted g/mile for the SUV and the light-duty pick-up truck.

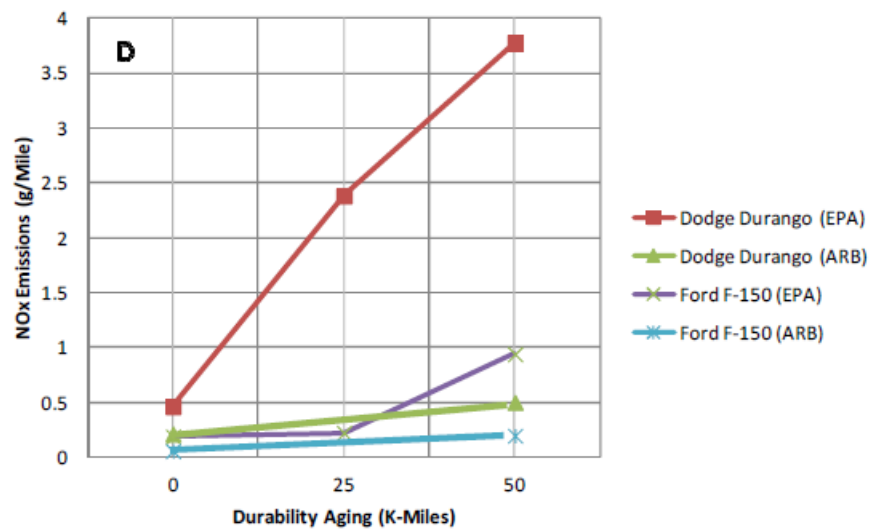


Figure 13. Emissions of oxides of nitrogen (NOx) in weighted g/mile for the SUV and the light-duty pick-up truck.

The same general conclusions can be made for the SUV and the light-duty pick-up truck as were discussed for the passenger cars. The ARB converter on the F-150 offers a 30-40% benefit over the federal aftermarket converter for all four criteria pollutants after the first 25,000 miles of aging. The benefit increases to 60% for HC and CO and 80% for NOx after the full 50,000-mile aging. The Durango equipped with an ARB converter offers a 60% advantage for HC and CO and an 85% benefit in NOx reduction versus the federal converter over the entire aging period. The emission level for the Durango equipped with an EPA aftermarket converter is approximately 3 g/mile

of HC + NO_x weighted on the FTP after the mid-aging point, increasing to almost 5 g/mile after 50,000 miles.

The average emission benefit for the five vehicles was found to be 77% lower NO_x, 60% lower HC, and 63% lower CO emissions by using the latest ARB aftermarket converter technologies versus using the federal aftermarket converters. The data clearly indicated that significant emission benefits could be achieved by revising federal aftermarket converter requirements and emission limits to match those required by California.

A summary of this test program was published as an SAE paper in April 2013 (see: papers.sae.org/2013-01-1298/).

6.0 Aftermarket Converter Programs in Other States

6.1 New York

In December 2012, the New York Department of Environmental Conservation (NY DEC) amended their regulations to implement California's LEV III light-duty vehicle regulation. (NY DEC originally adopted California's new light-duty vehicle standards in 1993 under Section 177 of the Clean Air Act.) As part of this process, NY DEC also incorporated ARB's 2009 aftermarket converter regulation. However, NY DEC delayed implementation of the aftermarket portion of ARB's LEV III regulation until June 1, 2013, to give manufacturers and their dealers additional time to transition to the new requirements. Subsequently, in May 2013, NY DEC issued a discretionary enforcement letter saying that NY DEC will not enforce the provisions of the aftermarket converter regulation until January 1, 2014. However, DEC expected all regulated parties to use best efforts to comply with the provisions of the regulation starting on June 1, 2013.

The New York regulation requires that only newly manufactured, ARB-approved aftermarket converters can be sold, advertised, or installed on MY 1993, 1994, and 1996 and newer New York State-registered vehicles that are ARB- or 50-state-certified. Vehicles that are MY 1995, 1992 or older, or are EPA-certified can continue to have federal aftermarket converters installed. To match California's aftermarket requirements, the state banned the sale of used or remanufactured converters. The state, however, continued to allow the sale of federal converters for use on non-New York registered vehicles and for out-of-state distribution.

New aftermarket catalytic converters for CARB-certified and federally certified vehicles are required to:

- Display a certification stamp or label on the catalytic converter shell. The label or stamp must display the CARB Executive Order approval number, the part number, date of manufacture, and proper installation direction.
- Comply with a vehicle's original emissions certification limits.

- Be compatible with the onboard diagnostic system (OBD II) on 1996 and newer vehicles.
- Be covered by a warranty for a period of 5 years or 50,000 miles of use. The warranty will cover failures related to construction defects, performance defects, and OBD II compatibility issues.

For more information on New York's new aftermarket converter requirements, go to: www.dec.ny.gov/chemical/87411.html.

6.2 Maine

Maine adopted California's 2009 aftermarket converter regulation in December 2012 and plans to begin implementing the requirements on June 1, 2015.

6.3 Vermont

Vermont adopted California's 2009 aftermarket converter regulation in December 2012, but the state is not currently enforcing the requirements. State officials have said they have concerns about the lack of availability of ARB-approved aftermarket converters and inadequate state resources to implement and enforce the requirements.

6.4 Ozone Transport Commission

The Ozone Transport Commission (OTC) has led in the state efforts to revise the federal aftermarket converter program. OTC is a multi-state organization created under the Clean Air Act responsible for advising EPA on transport issues and for developing and implementing regional solutions to the ground-level ozone problem in the Northeast and Mid-Atlantic regions. OTC members include: Connecticut, Delaware, the District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and Virginia.

In June 2009, OTC adopted a statement requesting that EPA review and update the requirements of its federal aftermarket converter program. In April 2011, OTC sent a letter to EPA recommending specific regulatory changes to the federal aftermarket converter program. In June 2014, OTC formally adopted a model rule for states in the Ozone Transport Region (OTR) to adopt more stringent aftermarket catalytic converter requirements based on ARB's 2009 amended aftermarket regulation.

The model rule essentially provides the language necessary for an OTC state to adopt California's aftermarket catalyst program. For a model rule to be fully implemented, each state must follow their own regulatory process to incorporate the model rule language into their state code of regulations. The model rule allows only CARB-approved converters to be installed as an aftermarket emission control part on gasoline passenger cars after the original converter exceeds the emissions warranty. This is identical to California's regulation, which allows only ARB-approved devices to be installed on all vehicles. (Note: OTC's model rule is different than the requirements

adopted by New York, which allows federal converters to be installed on federally certified vehicles.) Unlike California's program, OTC's model rule has optional language allowing used converters to be installed on OBD-equipped vehicles.

In support of the model rule, OTC calculated the potential emission benefits of implementing their recommended catalytic converter program in the OTR. The analysis used the results of MECA's 2012 test program showing the benefits of installing CARB aftermarket converters in lieu of federal converters (see Section 5.0). OTC estimated that an updated aftermarket catalytic converter program in the OTR could reduce NOx emissions by 13,000-20,000 tons per year in 2015, as well as reduce NMHC by 3,000-4,000 tpy and CO by 28,000-44,000 tpy.

In the development of the model rule, MECA raised a number of concerns regarding enforcement and implementation of California standards in the other 49 states. Of particular concern is the ability of a state to enforce the standards when neighboring states have different requirements, making it possible for vehicles to travel out of state for repair. In the absence of a visual inspection and confirmation that the proper converter is installed, as required by California, owners will install the cheaper, federal converters to pass an emissions inspection.

In response to MECA's list of implementation issues, first developed following NY DEC's adoption of CARB's aftermarket converter standards in December 2012, OTC published a guidance document that helps states interpret the model rule and address some of these issues. Included in this guidance document is an installer check list and decision flow chart to help installers identify the right converter to install. To address the lack of CARB aftermarket converter coverage on federal vehicles that are not included in CARB executive orders, the decision tree offers a sequence of options. The first option recommends that the installer identify a CARB converter for a California certified vehicle with an equivalent year, make, model, and engine, or install an OEM converter. If an OEM converter is not available, the document directs the installer to find a converter for a vehicle with a similar engine displacement, exhaust configuration, and converter location. If none of these options are available to the installer, they are directed to contact a state representative for an exemption waiver to install an EPA-approved converter on the vehicle.

For documentation on OTC's aftermarket catalytic converter model rule, go to: www.otcair.org/document.asp?fview=meeting.

7.0 Aftermarket Converter Programs in Other Countries

7.1 European Union

The European Union (EU) adopted requirements for the type approval of replacement converters as separate technical units by Annex XIII of the Commission

directive 98/77/EC in October 1998. In 1999, an estimated 1.3 million replacement converters were sold.

The EU requirements regarding emissions, like the U.S., are performance-based, but, rather than having a specific percent reduction for each pollutant as in the U.S., the EU program requires that the emission reduction performance of the replacement converter must be equal to or better than the OE converter for CO, HC+NO_x, and PM. The program requires two sets of back-to-back emission tests to compare the emission control efficiency of the replacement converter to the OE converter. The testing includes one vehicle that represents the “worst case” application for the converter and another vehicle that is representative of the vehicle applications on which the replacement converter will be utilized. The tests are conducted over the EU driving cycle.

The emission requirements for each pollutant are as follows:

- 1) The mean value of three tests with the replacement converter shall be less than or equal to 0.85 times the mean value of three tests with the original catalytic converter plus 0.4 times the EU limit value according to the type approval of the vehicle divided by, if applicable, the deterioration factor; and
- 2) The mean value of three tests with the replacement converter shall be less than or equal to the EU limit value according to the type approval of the vehicle divided by, if applicable, the deterioration factor.

The converter manufacturer is required to demonstrate durability by one of two prescribed approaches. First, the manufacturer may apply an assigned deterioration factor of 1.2 for CO and HC+NO_x for spark-ignition engines, and a deterioration factor of 1.1 for CO, 1.0 for HC+NO_x, and 1.2 for PM for compression-ignition engines. The second approach is to verify the durability of the device by conducting an aging test for 80,000 km. Manufacturers in Europe generally use the assigned deterioration factors rather than the aging test to demonstrate durability. This practice allows for the possibility of aftermarket converters being approved with unproven durability.

In addition to these emission-related requirements, the replacement catalytic converter also has to comply with general construction specifications and requirements regarding noise and exhaust backpressure (Annex II to Directive 70/157/EEC). The EU also requires that the converters be labeled and that the manufacturer complete an application process and receive an official approval. Converter manufacturers who fail to supply products that conform to the approval granted can lose their approval certificate.

7.2 Mexico

In 1999, Mexico City introduced a voluntary converter replacement program for 1993 model-year passenger cars. The governments of Mexico City and the State of Mexico administer the program. The program was designed to give an incentive to vehicle owners to replace converters in order to obtain a “zero sticker” that would allow them to drive on all days of the week. In 2000, the program was extended to cover model

years 1994 and 1995. Also, participation in the replacement program became mandatory for anyone wishing to obtain a zero sticker.

There is a formal approval process that includes a requirement that manufacturers have their converters tested at an approved, independent testing facility. The converters must meet minimum emission reduction performance requirements of 70% for CO, 70% for HC, and 60% for NOx. Currently, authorities also require that the replacement converter contain a minimum loading of precious metals (20 grams per cubic foot) and a 0.7 grams per converter minimum precious metal content. There is no durability demonstration requirement, but the program requires a physical integrity warranty of 60,000 kilometers or two years, whichever occurs first. The program in Mexico City requires that converters be labeled and also that a bond be posted as a condition for receiving an approval.

Since the replacement converter program began, authorities estimate that hundreds of thousands of replacement converters have been installed.

8.0 Vehicle Inspection and Maintenance

An essential component of any aftermarket converter replacement program is some form of enforcement or state-operated vehicle inspection and maintenance (I/M) program. Vehicle emission inspections are a tool employed to ensure that vehicles meet applicable exhaust emission standards under normal operating conditions. I/M programs consist of measuring emissions and requiring consumer repairs when those emissions exceed specified levels. These inspections most commonly use exhaust gas analysis test methods using a direct reading instrument on a chassis dynamometer. It is not typically possible to administer a certification-type emissions test, so I/M tests generally tend to be less precise and often rely on emissions test measurements that comprise only a fraction of certification test measurements. In 1996 and newer model year vehicles equipped with OBD systems, it may be sufficient to download information from the OBD computer module to check if any emission system malfunction codes were recorded.

Two different types of inspections are commonly performed:

- 1) periodic emission checks in which the vehicle is inspected at an approved testing station at regular time intervals (i.e., annual or biennial), and
- 2) spot inspections performed on a random basis by pulling vehicles off the road for on-site inspection (generally referred to as “roadside inspections”).

Periodic I/M tests are a critical component of a comprehensive vehicle emissions reduction strategy. 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. An I/M program is the most effective way to ensure that converters remain on vehicles and continue to function properly to deliver the expected emission benefits.

9.0 Conclusion and Recommendations

Since their introduction in 1975, catalytic converters continue to be the single most important technology for the control of emissions from gasoline-powered motor vehicles. The technology has been proven durable and effective for over 35 years on a wide range of engines and vehicles. The advances in catalyst and manufacturing technology that have been developed for new vehicles are being incorporated in advanced aftermarket replacement converters.

MECA believes that significant emission reductions in NO_x, CO, and HCs are achievable by strengthening the requirements of the federal aftermarket converter exemption policy. MECA has supported EPA's efforts in the review of their 1986 aftermarket converter program. MECA continues to believe that a more stringent federal aftermarket converter policy is the most effective approach toward cleaning up the fleet of in-use light-duty vehicles. This will eliminate the complexity of enforcing on out-of-state vehicles or illegal converters installed in neighboring states that may have different requirements. In addition, a federal policy would make available the most advanced aftermarket technology for federally certified vehicles that are not covered by existing CARB Executive Orders.

California's revisions to their aftermarket converter program in 2009 brought new aftermarket converter performance back in-line with levels necessary to ensure that vehicles designed to meet current standards would continue to have low emissions throughout their lifetime. Higher emission reductions from motor vehicles that require catalytic converter replacements are both necessary and achievable, and the improved performance and durability of advanced OBD II-compliant aftermarket catalytic converters meeting more stringent federal requirements would provide for significant additional benefits beyond those being achieved today.

To be effective, a replacement converter program should have at a minimum the following program elements:

- A government administered application review/approval process;
- Mass-based emission reduction limits to the OEM certification limit of vehicles;
- Durability testing including the option to use accelerated chassis dynamometer aging;
- Emission and mechanical integrity warranties of 5 years/50,000 miles;
- Enforcement initiatives including periodic inspection and maintenance checks; and
- Record-keeping requirements.

In addition to the air quality benefits gained from an effective light-duty gasoline vehicle aftermarket catalyst program, further emission reductions can be achieved by incorporating light- and medium-duty diesel vehicles into an aftermarket converter program. As noted, the catalyst technology that has been used on 1994-2006 light- and

medium-duty diesel vehicles employs traditional oxidation catalysts that are readily available and durable. This catalyst technology could be easily applied to lower-cost aftermarket catalysts to replace missing or damaged catalysts in the existing light- and medium-duty diesel fleet. As the population of light- and medium-duty diesel vehicles increases in the U.S. over the next several years, so will the need for an effective converter replacement program for these vehicles.

10.0 Resources

1. Fact sheet on the U.S. EPA's interim aftermarket converter policy (September 2000):
epa.gov/otaq/cert/factshts/catcvrts.pdf
2. California's aftermarket catalytic converter program:
www.arb.ca.gov/msprog/aftermktcat/aftermktcat.htm
3. ARB Staff Report: "Initial Statement of Reasons for Rulemaking: Public Hearing to Consider Amendments to Regulations Regarding New Aftermarket Catalytic Converters and Used Catalytic Converters Offered for Sale and Use in California (September 7, 2007)," www.arb.ca.gov/regact/2007/amcat07/isor.pdf
4. "MECA Recommendations for the Successful Implementation of New Aftermarket Converter Regulations" (July 2013):
www.meca.org/resources/MECA_Aftermarket_Implementation_Issues_final_071513.pdf