Catalytic Converter Retrofit for Gasoline-Powered Vehicles: Technical Issues and Program Implementation Considerations

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The Manufacturers of Emission Controls Association
1660 L Street NW  Suite 1100  Washington, DC 20036
tel: (202) 296-4797  fax: (202) 331-1388
EXECUTIVE SUMMARY

A number of countries are considering the implementation of a catalyst retrofit program for gasoline-powered passenger cars and light trucks as part of a strategy to reduce emissions from existing, high-polluting vehicles. Depending on such factors as the nature of the air quality problems, the make-up of the vehicle fleet, and the availability of unleaded gasoline, a properly designed, implemented, and enforced catalytic converter retrofit program may be an attractive option. An improperly designed and administered program, however, can result in no air quality gains, a waste of financial resources, and the risk of losing public support for all motor vehicle emission control programs.

Over the past 24 years, catalytic converters have been installed on over 300 million vehicles around the world and, presently, approximately 85 percent of the new passenger cars manufactured worldwide are equipped with catalytic converters. The concept behind a catalytic converter is that it causes a chemical reaction to occur without being changed or consumed. Therefore, with proper maintenance, use, and fueling, it will perform its function for the life of the vehicle. Catalytic converters can be designed to control hydrocarbons (HC) and carbon monoxide (CO) (oxidation catalytic converters) or to control HC and CO as well as oxides of nitrogen (NOx) (three-way catalytic converters).

Five important principals should be met in designing and implementing a successful catalyst retrofit program: 1) unleaded gasoline (maximum of 0.015 grams of lead per liter) must be readily available and used; 2) the vehicle’s age, type, and mechanical condition should be important factors in considering the appropriateness of retrofit; 3) emission performance levels and the duration for which the retrofit system must meet those levels (“useful life”) should be rigorous, but less severe than required for new vehicles designed to meet stringent emission standards; 4) an administrative program is needed to certify that retrofit equipment meets the emission reduction standards and useful life requirements and to ensure that the equipment is properly installed; and 5) periodic vehicle inspections should be made to verify that the vehicles are receiving proper maintenance and the retrofit systems are working properly.

Vehicles not previously equipped with a catalytic converter can be retrofitted with either an oxidation catalytic converter (HC and CO control) or a three-way catalytic converter (controls HC, CO, and NOx). The procedures, equipment and estimated costs for a proper catalytic converter retrofit program are discussed in the report. Retrofitting a three-way converter system is more complex since such converters require the addition of a feedback control system.

A successful program must be clearly defined by law (either legislation or regulations) to minimize confusion and abuses. Also, using incentives to encourage retrofits are needed. Experience has shown that purely voluntary programs will not succeed and that programs mandating retrofits may prove extremely unpopular. Incentives in the form of cash subsidies, tax rebates, or exemptions from driving restrictions that apply to other high polluting vehicles have been successful ways to promote converter retrofits.
Education is an essential element of a successful catalytic converter retrofit program. The public must be educated on the public health benefits of the program, as well as the importance of having the retrofit performed correctly and the vehicle properly maintained, fueled, and used once the converter has been installed. Mechanics and technicians also must be trained to ensure that retrofits are properly performed. The retrofit program must be carefully monitored and enforced. Enforcement should include regular inspections and oversight of installation shops and individuals performing the retrofits.

Catalyst retrofit programs require careful planning, dependable unleaded fuel supplies, and effective oversight of equipment suppliers, installation facilities, and vehicle operations. If a retrofit program is properly designed and enforced, it can result in meaningful reductions in harmful pollution from existing high-emitting passenger cars and light trucks.
1.0 INTRODUCTION

A growing number of countries worldwide have implemented, or are in the process of implementing, programs to substantially reduce emissions from new passenger cars and light-duty trucks. Some of these countries are evaluating strategies to reduce emissions from the high-polluting existing fleet of vehicles to effect an immediate reduction in pollution.

One strategy is implementing a catalyst retrofit program for existing gasoline-powered vehicles. Significant administrative, implementation, and technical challenges exist in implementing an effective retrofit program. Depending on such factors as the nature of the air quality problems, the make-up of the vehicle fleet, and the costs of other emission control strategies, a properly designed, implemented, and enforced catalytic converter retrofit program may be an attractive option which can achieve significant immediate reductions in harmful pollutants. An improperly administered program can result in no air quality gains, a waste of financial resources, and the risk of losing public support for all motor vehicle emission control programs.

The Manufacturers of Emission Controls Association (MECA) has received inquiries from around the world regarding the feasibility and advisability of implementing a catalytic converter retrofit program for gasoline-powered vehicles. This document was prepared to provide information on technical and administrative issues related to a retrofit program and to review retrofit programs that have been implemented.

2.0 CATALYTIC CONVERTER TECHNOLOGY

Before discussing issues related to retrofit, a brief review of catalytic converter technology is appropriate. The concept behind a catalyst is that it causes chemical reactions to occur without being either changed or consumed. Therefore, a catalyst on a properly maintained and fueled vehicle will perform its function for the life of the vehicle.

The catalytic converter contains a catalyst in a honeycomb form and is housed in a stainless steel canister. There are no moving parts, just large areas of interior surfaces coated with catalytic metals within the honeycomb structure. A thin porous catalyst layer is applied to the interior surfaces. Within this layer are small sites of catalytic metal -- platinum (Pt), Rhodium (Rh), and/or Palladium (Pd). The catalyst layer is thin and only a few grams of the precious metals are used. The exact combinations of these precious metals differ according to whether the particular converter is intended to control only carbon monoxide (CO) and hydrocarbons (HC) or must also control oxides of nitrogen (NOx). In any case, by the time most of the harmful gases that enter the catalyst emerge from the other end, they have been changed to harmless water vapor, carbon dioxide, and nitrogen.

2.1 Oxidation Catalytic Converter (Two-Way Converter) -- The first type of converter introduced in the United States was the oxidation converter, which is designed to oxidize only
hydrocarbons and carbon monoxide. It is called an oxidation catalytic converter because the transformation of harmful pollutants into harmless gases is accomplished by oxidation -- as in combustion. The substrate surfaces inside the converter are covered with a thin porous catalytic layer that contains a combination of platinum and/or palladium. The hydrocarbon, carbon monoxide, and oxygen molecules are adsorbed within the catalytic layer and react to form carbon dioxide and water vapor which go out the tailpipe.

### 2.2 Three-way Catalytic Converter

As its name implies, a three-way catalytic converter (TWC) can simultaneously remove all three major pollutants - oxides of nitrogen, as well as carbon monoxide and hydrocarbons. It does this by reducing the NOx to nitrogen and oxygen, while oxidizing the CO and HC to carbon dioxide and water vapor. To accomplish these different chemical reactions, the air/fuel mixture has to be precisely metered so that it is at the perfect ratio needed to complete combustion without an excess of either air or fuel. An engine management system (sometimes referred to as computer command) is needed to monitor the air/fuel ratio and control the fuel metering system. Feed back (closed loop) control is provided by an oxygen sensor which provides a signal to indicate the air/fuel (A/F) ratio to adjust the fuel metering system according to the perfect A/F mixture. Using fuel injection and feed back engine management, it is possible to use a three-way converter to control HC, CO, and NOx. The three-way converter needs only one catalyst bed, using a combination of platinum, rhodium, and/or palladium.

With carburetor fuel metering systems it is more difficult to attain the precise air/fuel ratio necessary, and consequently, the converter sometimes is divided into two beds; the first bed is used primarily for reduction of NOx and the second bed for oxidation of HC and CO with air injected between the two beds.

Since the early 1980s, three-way converters have been installed on most U.S. new cars, usually in conjunction with electronic fuel injection systems.

### 2.3 Effective Catalyst Operation Requires Proper Chemistry and Temperature

For a catalytic converter to function effectively, it is essential that the proper chemistry and operating temperature be present. These factors are critical to consider when retrofitting a converter on a vehicle which was not originally designed for, or equipped with, such controls.

#### 2.3.1 Chemistry

For oxidation catalytic converters, it is important to insure the presence of adequate oxygen to complete the oxidation process. This may necessitate incorporating devices which add air to the exhaust. As mentioned above, for three-way catalytic converters, very precise control of the air/fuel mixture is required. Consequently, closed-loop systems should be used (see discussion below).
2.3.2 Temperature

The placement of the converter in the exhaust system relative to the engine is important to insure that the exhaust temperature is sufficient for the operating range of the catalyst. If the converter is too close to the engine, it may be exposed to excessive temperatures which could damage the catalyst.

3.0 CATALYTIC CONVERTER RETROFIT TECHNICAL CONSIDERATIONS

Before discussing the technical considerations for retrofit, five preliminary points need to be made. First, unleaded fuel must be used. If unleaded gasoline (maximum of 0.015 grams per liter lead) is not readily available or vehicle operators are able to fill their tanks with leaded fuel, then a catalytic converter retrofit program should not be implemented. A retrofit program for Liquid Petroleum Gas (LPG) or Compressed Natural Gas (CNG) is also possible. Second, the vehicle’s age, mechanical condition, and engine/exhaust system design are important factors in considering the appropriateness of retrofit. Third, emission performance and useful life requirements of the retrofitted vehicle should be less severe than required for new vehicles designed to meet current emission standards. Fourth, an administrative program is needed to certify that the retrofit equipment meets the performance and useful life requirements and to ensure that the equipment is installed correctly. Finally, periodic vehicle inspections should be conducted to verify that the vehicles have received proper maintenance and that the retrofit systems are working correctly.

Vehicles can generally be divided into three categories:


3.1 Types of Catalytic Converter Retrofit Programs

Based on the vehicle types shown above, three general types of converter retrofit programs are possible:

1. Oxidation or TWC catalytic converters installed in previously uncontrolled vehicles.
2. Upgrade existing oxidation converter to TWC type with retrofit closed-loop air/fuel ratio control.

3. Upgrade existing TWC converter with new technology TWC or add supplemental converter(s).

The focus of this document will be on the first category of retrofits. The second and third categories are discussed in a MECA document entitled *Emission Control System Upgrades for Gasoline-Powered Light-Duty Vehicles*.

### 3.2 Retrofit Program for Vehicles Not Previously Equipped with Converters

Vehicles not previously equipped with a catalyst can be retrofitted with either an oxidation catalyst which will control hydrocarbons (HC) and carbon monoxide (CO) or a three-way catalyst which will simultaneously control HC, CO, and oxides of nitrogen (NOx). Retrofitting a vehicle with a three-way converter requires the addition of a feedback control system. Installing a catalytic converter, whether oxidation or three-way, without also adjusting or actively controlling the air fuel ratio, will not produce the full emission reduction of which the converter is capable.

#### 3.2.1 Oxidation Catalyst Retrofit

Vehicles retrofitted with an oxidation catalyst retrofit would need the following modifications:

1. Rebuild carburetor with modified jets for lean limit calibration or add an air pump or pulse air system. Both of the above should be designed to provide sufficient air for the oxidation catalyst to function.

2. Upgrade ignition system to high energy (30 kV minimum) capability, if not already fitted.

3. Replace spark plugs, wires, and sleeves with high energy, thermal-resistant and waterproof components, if not already equipped.

4. Replace any cracked, brittle, or broken vacuum hoses.

5. Install proper sized converter taking into consideration such factors as engine type, size and type of vehicle, and emission reduction goals.

6. A dash pot may have to be added to the throttle to minimize deceleration misfire.
3.2.2 Three-Way Catalyst Retrofit

Vehicles retrofitted with a three-way catalyst and the accompanying feed-back control system to insure that it operates properly would need the following modifications:

1. Install oxygen sensor (heated type is preferred) in exhaust pipe ahead of converter installation location.

2. Install air/fuel control system. This system may utilize the vehicle's electronic fuel injection computer, if equipped, or include an independent computer and air/fuel control actuator, particularly if the vehicle uses carburetion or mechanical fuel injection. (These systems have been used for many years in aftermarket conversions of used vehicles imported into the U.S. which have to be modified to meet the EPA emission specifications and for propane/CNG conversions of gasoline-powered vehicles.)

3. Upgrade ignition system to high energy capability (30 kV minimum), if not already fitted.

4. Replace spark plugs, wires, and sleeves with high energy, thermal-resistant and water proof components, if not already equipped.

5. Replace any cracked, brittle, or broken vacuum hoses.

6. Install proper sized converter.

With any catalyst retrofit, the fuel tank of a vehicle which has used leaded gasoline should be "flushed" by operating the vehicle on at least one full tank of unleaded gasoline prior to installing the catalyst. Also, retrofitted vehicles should have a label fixed at the fuel tank inlet which states "use unleaded gasoline only" and if practical and appropriate, a gas tank resizer should also be installed to prevent leaded gasoline from being used.

3.3 Cost and Effectiveness of Retrofit

Based on publicly available cost estimates for parts, the approximate range of costs for the modifications described above, if purchased in the U.S., would be:
Catalytic Converter Retrofit for Gasoline-Powered Vehicles

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ignition system tune-up and upgrade to high energy, if required</td>
<td>$15-25</td>
</tr>
<tr>
<td>Electronic ignition upgrade kit (extends point life by reducing current flow)</td>
<td>$35.00 - $50.00</td>
</tr>
<tr>
<td>Carburetor overhaul kit or air injection kit (for oxidation converter systems)</td>
<td>$30-85</td>
</tr>
<tr>
<td>Catalytic converter (depends on size and efficiency)</td>
<td>$50-150</td>
</tr>
<tr>
<td>Universal retrofit closed loop system (computer, oxygen sensor, wiring, control valve) suitable for gasoline or propane vehicle with carburetor or fuel injection</td>
<td>$150-300</td>
</tr>
<tr>
<td>Throttle body fuel injection closed loop system (computer, oxygen sensor, wiring, throttle body, adaptor plate, air cleaner) suitable for upgrading carburetor equipped vehicle</td>
<td>$400-800</td>
</tr>
<tr>
<td>Propane (CNG or LPG) closed loop retrofit system (computer, oxygen sensor, wiring, carburetor, propane tank, fuel lines, evaporator, propane carburetor) suitable for use where unleaded gasoline is not available</td>
<td>$1200-1800</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Preparation and Installation labor</th>
<th>HOURS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tune-up and electronic ignition</td>
<td>1</td>
</tr>
<tr>
<td>Install catalytic converter</td>
<td>1</td>
</tr>
<tr>
<td>Install universal retrofit system</td>
<td>2</td>
</tr>
<tr>
<td>Install throttle body fuel injection system</td>
<td>3</td>
</tr>
<tr>
<td>Install propane system</td>
<td>4</td>
</tr>
</tbody>
</table>

Footnotes:
1) Prices are for production quantities of standard parts at U.S. factory or primary distributor.
2) Price range reflects different quantity, quality and performance levels.
3) Labor estimates are typical of high volume installation center using standardized components and equipment.

The emission reduction potential will depend on such factors as the general mechanical and tune-up condition of the vehicle, the design of the converter (i.e., catalyst loading and volume) and the air/fuel ratio management provided by the vehicle.

Below is sample data from a number of vehicles, generated by one of MECA's members, which illustrates the level and range of control potential of converter retrofits. The data shown is based on testing with unaged converters. Some deterioration of converter performance is expected over time. As can be seen, the emission performance with air fuel ratio control is superior to without control for the same converters.
### TWC Converter Only:

<table>
<thead>
<tr>
<th>Description*</th>
<th>FTP Emissions (g/km)</th>
<th>FTP Emissions (g/mi)</th>
<th>% Estimated Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>MY/DISP/WT/CAT</td>
<td>HC</td>
<td>CO</td>
<td>NOx</td>
</tr>
<tr>
<td>86/1.3L/2500/A</td>
<td>0.53</td>
<td>9.53</td>
<td>0.05</td>
</tr>
<tr>
<td>93/1.5L/2500/B</td>
<td>0.63</td>
<td>9.34</td>
<td>0.08</td>
</tr>
<tr>
<td>73/5.2L/4500/C</td>
<td>0.57</td>
<td>5.44</td>
<td>1.80</td>
</tr>
<tr>
<td>93/2.0L/3000/D</td>
<td>0.42</td>
<td>2.84</td>
<td>0.60</td>
</tr>
<tr>
<td>Average of 4 cars</td>
<td>0.53</td>
<td>6.79</td>
<td>0.63</td>
</tr>
</tbody>
</table>

### TWC Converter with Closed-Loop AFR Control System

<table>
<thead>
<tr>
<th>Description</th>
<th>FTP Emissions (g/km)</th>
<th>FTP Emissions (g/mi)</th>
<th>% Estimated Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>MY/DISP/WT/CAT</td>
<td>HC</td>
<td>CO</td>
<td>NOx</td>
</tr>
<tr>
<td>86/1.3L/2500/A</td>
<td>0.20</td>
<td>1.49</td>
<td>0.16</td>
</tr>
<tr>
<td>93/1.5L/2500/B</td>
<td>0.11</td>
<td>0.73</td>
<td>0.24</td>
</tr>
<tr>
<td>93/1.5L/2750/B</td>
<td>0.20</td>
<td>1.03</td>
<td>0.19</td>
</tr>
<tr>
<td>93/1.6L/3000/B</td>
<td>0.19</td>
<td>1.78</td>
<td>0.38</td>
</tr>
<tr>
<td>73/5.2L/4500/C</td>
<td>0.56</td>
<td>3.88</td>
<td>1.85</td>
</tr>
<tr>
<td>69/1.5L/2000/E</td>
<td>0.34</td>
<td>3.79</td>
<td>0.52</td>
</tr>
<tr>
<td>93/1.8L/2375/D</td>
<td>0.17</td>
<td>2.06</td>
<td>0.50</td>
</tr>
<tr>
<td>93/2.0L/2875/D</td>
<td>0.20</td>
<td>2.45</td>
<td>0.30</td>
</tr>
<tr>
<td>Average of 8 cars</td>
<td>0.25</td>
<td>2.15</td>
<td>0.52</td>
</tr>
</tbody>
</table>

*Key: MY=Model Year; DISP=Displacement; WT=Weight; CAT=Catalyst Model; FTP=Federal Test Procedure; AFR=Air/Fuel Ratio

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### 4.0 Administrative Considerations

Before implementing a catalytic converter retrofit program, several factors must be carefully evaluated:

- the nature of the air quality problem;
- the make-up of the local vehicle population;
Catalytic Converter Retrofit for Gasoline-Powered Vehicles

- the nature, scope, and costs of a retrofit program;
- the availability and costs of other emission reduction control strategies;
- the availability of resources to safely and properly implement the program; and
- the availability of enforcement, including inspection/maintenance, to assure compliance.

The nature of the air quality problem is important because it will influence the type of retrofit considered. For example, if the local air quality problem is principally carbon monoxide, an oxidation (two-way) converter retrofit program would be most appropriate, with the benefit of reducing HC emissions. On the other hand, if the problem is ground level ozone, a three-way converter (TWC) retrofit program might be the preferred option because it would provide control of HC and NOx -- the precursors to ozone -- along with the control of CO.

The make-up of the existing vehicle fleet is an important factor in assessing the feasibility, scope and costs of a retrofit program. In considering a retrofit program, it is prudent to target vehicle populations whose maintenance can be controlled, such as fleets. Taxi fleets are good candidates because they also are driven many miles annually and likely contribute more emissions on a per vehicle basis than a privately-owned vehicle.

4.1 Legislation and Incentives

A successful retrofit program must be clearly defined by law (either legislation or regulations). Without a clear description of the required program elements, chaos, confusion and abuse are sure to follow. Further, the supporting industry that will be investing in equipment and personnel needed to supply the control technology cannot make commitments without a clearly specified program with all the elements.

Incentives are a proven means necessary to the success of a retrofit program. Experience has shown that a purely voluntary program will not succeed. Programs which mandate retrofits may prove to be extremely unpopular, particularly when the vehicles most likely to be the target for retrofits are owned by people with the least available resources to pay for such retrofits. Incentives in the form of cash subsidies, tax rebates or exemptions from driving restrictions that might otherwise apply have been successful means to promote converter retrofits.

4.2 Elements of a Retrofit Program

A retrofit program should contain the following specific elements:

- The retrofit reduction goals/standards to be met over a specified period following the retrofit.
The specific elements of the program will need to be developed to fit the particular purpose and setting for the program. For example, the emission reduction requirements can be based on either performance standards or design standards, or some combination of both. Regardless of the type of standards, an emission testing demonstration should be required. The test should demonstrate that the retrofit system can meet the required emission reduction levels and that the system is durable. In those situations in which a government agency tests and approves retrofit systems, performance standards may be preferred. On the other hand, where the government agency does not have access to emission test facilities, but where the product and product design can be inspected, design standards may be more appropriate.

One of the most important elements of a retrofit program is selecting the emission reduction standard. If the standard is too lenient, emission reductions will be insignificant. If the standard is too stringent, then the retrofit system will be very complex and expensive. If the system is too expensive, it will not be widely used and again the overall emission reductions will be insignificant. Vehicles with retrofit systems should not be expected to have the same high emission reduction performance (80-95%) as new vehicles designed from the beginning to have low emissions. It is better to establish a modest emission reduction goal (60-75%) for each vehicle which can be achieved on a large number of vehicles with modest expense. Also, retrofit system must be durable and last for the period specified by the program.

4.3 Education and Enforcement

Education is also essential for a retrofit program. The public must be educated on the public health benefits of the program, as well as the importance of having the retrofit performed correctly and the vehicle properly maintained, fueled and used once the converter has been installed. In particular, the public must appreciate the health benefits of using unleaded gasoline, along with the understanding that unleaded fuel is needed to reach the target of the retrofit program, i.e., reducing pollution. Mechanics and technicians must be educated and trained to properly install and inspect the retrofits. Mechanics and technicians must be certified and
monitored. The chances for a successful program are enhanced if the vehicles targeted for retrofit are part of government or private fleets.

The retrofit program must be vigorously enforced. This includes regular inspection and monitoring of the installation shops and individuals performing the retrofits. Where violations are detected, the penalties should be substantial and well-publicized. Finally, the retrofitted vehicles should be inspected periodically to insure that the installed retrofitted vehicles are performing properly and emissions remain within target levels.

5.0 PRIOR EXPERIENCE WITH RETROFIT PROGRAMS

Programs to encourage retrofit of catalytic converters on gasoline-powered vehicles have been initiated in several countries around the world. These programs provide some guidance to others considering such programs.

5.1 Mexico

SEDESOL (Secretaria de Desarrollo Social), the Secretary of Social Growth, is the federal environmental protection agency in Mexico. SEDESOL developed a catalytic converter retrofit program several years ago. The program is designed to cover all post-1980 vehicles which are currently not converter equipped.

SEDESOL worked with local suppliers and catalyst companies to develop a universal catalyst technology which it hopes will provide the best across-the-board results. SEDESOL regulations define the noble metal loading and ratios, catalyst volume, performance characteristics (minimum conversion efficiency), and durability. SEDESOL requires all companies seeking approval for the use of a catalytic converter to undergo testing of the converter in the SEDESOL Laboratory. A certified letter of manufacture from the converter supplier, which confirms the construction of the converter, is also required. Once this approval is granted, the company may distribute and install the approved converters.

The actual retrofit installations are carried out by private companies that have been granted the concession from the government. Installation centers will be strategically located in populated areas. These installation center operators must use only SEDESOL-approved retrofit kits, and have the ability to operate the centers according to SEDESOL guidelines. The approved kits incorporate closed-loop control of LPG (propane) fuel systems because unleaded gasoline supply was previously unreliable. Because of the high cost of these conversion kits, only commercial fleet vehicles have generally been retrofitted. A new program to approve lower cost kits with TWC catalysts and closed-loop retrofit of gasoline-powered vehicles is scheduled to begin in 1998.

The program is voluntary, and the incentive to retrofit is the removal of vehicle operating restrictions that otherwise would apply.
Currently, SEDESOL or other agencies are not aggressively inspecting installed retrofit systems. However, there is a mandatory two-year replacement of the catalysts which is assumed to compensate for the effects of deterioration. Future plans include annual inspection of all vehicles including those with retrofit systems.

5.2 **Germany**

Germany conducted a voluntary retrofit program using tax credits as an incentive. A vehicle which had an approved system installed received a special certificate. The certificate was then used to obtain a 550 DM credit (about $275 at the time the program was in operation) for a TWC converter only or a 1100 DM credit ($550) for TWC with closed-loop control. The tax credit offsets about 50% of the installation cost to the consumer. The converters used in this program were typically the original vehicle manufacturer's converter used on current production vehicles. Most of the vehicles involved in this program were Volkswagen, Mercedes, and BMW models. The German program focused primarily on privately owned vehicles. Since 1985, hundreds of thousands of vehicles have been retrofitted with catalysts. The program included several stages of increasingly stringent emission reductions with proportionally higher tax credits. The program is now being administered by individual German states and is expected to end around the year 2000.

5.3 **California**

In 1972, 100 vehicles were retrofitted with oxidation catalytic converters and each was driven for at least 20,000 miles. With the exception of two or three vehicles which were misfueled, the results were excellent. HC and CO emissions were reduced by more than 70%. Although the demonstration program was a technical success, no tax or other incentive or retrofit requirement was established. Consequently, no market for the retrofit converter developed.

In 1997, an emission upgrade program began in the County of San Diego. The program consisted of retrofitting a TWC catalyst and a closed-loop air/fuel ratio control system on vehicles originally equipped with oxidation catalysts and open loop engine controls. After 30,000 miles, the average emission reduction from 6 durability vehicles was 70% for HC, 68% for CO, and 50% for NOx based on the FTP-CVS emission test. Vehicle owners volunteer for the program and receive the kit at reduced cost. Most vehicles are high emitters which have failed emission inspection tests. Approximately 150 vehicles have been converted with similar results to those found with the durability vehicles.

6.0 **Conclusion**

Catalyst retrofit programs require careful planning, dependable unleaded fuel supplies, and effective oversight of the equipment suppliers, installation facilities, and vehicle operators. Programs should include retrofit of closed-loop engine management systems for best catalyst durability and emission benefit. Although difficult to implement and administer, vehicle retrofit
programs are an option for reduction of harmful pollutants from the existing motor vehicle population. Care should be taken in evaluating the costs and benefits of such a strategy based on specific vehicle populations and the particular air quality problems that need to be addressed for the area in which such a program might be implemented.

If the decision is made to proceed with a retrofit program, public education and effective enforcement are essential. Finally, an incentive must be established to bring about a significant number of actual retrofits. The incentive can be either in the form of mandatory requirements or economic incentives such as tax credits.