# Experience in the United States with Automobile Emission Control

## PLATINUM CONTRIBUTES TO A REMARKABLE SUCCESS

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*To mark the fifteenth anniversary of the passing of a series of Amendments to the Clean Air Act by the Congress of the United States of America, the author, who was formerly Deputy Assistant Administrator for Mobile Source Air Pollution Control at the U.S. Environmental Protection Agency, reviews the benefits resulting from that legislation.*

In late 1970, in a wave of euphoria following the ecological festival known as "Earth Day", and frustrated by the United States' growing pollution problems, Congress passed a series of sweeping Amendments to the Clean Air Act. Perhaps the most controversial aspect of these Amendments at the time was the inclusion of a set of technology-forcing emissions standards for carbon monoxide, hydrocarbon and nitrogen oxides emissions from automobiles. Now, some fifteen years later, it is generally agreed that the air is cleaner and the health of many Americans improved as a result of this programme. Indeed, it is not too rash to claim that this is probably the most successful regulatory programme carried out in the history of the United States of America.

## Trends in Emissions

Since the adoption of the 1970 Clean Air Act Amendments, emissions of carbon monoxide, hydrocarbons and nitrogen oxides from automobiles have declined greatly, as illustrated in Figures 1 to 4 (1). For example, Figure 1 illustrates the hydrocarbon emission standards for new automobiles during this period, actual emissions from the model year vehicles as they were driven by each of us and the emission rate from the entire population of automobiles in the same period. Figures 2 and 3 show similar curves for carbon monoxide and nitrogen oxides, respectively. These figures show that since 1970 the amounts of carbon monoxide, hydrocarbons and nitrogen oxides emitted per mile have declined significantly as newer vehicles with emission controls have replaced older, higher polluting ones. In fact, for the latest model year, the emission rates for hydrocarbons, carbon monoxide and nitrogen oxides per mile driven have been reduced by 84 per cent, 86 per cent and 56 per cent, respectively, compared to uncontrolled vehicles. Of course, some of this gain has been offset by increased numbers of vehicles and by the greater mileage driven. However, in spite of an almost 60 per cent increase in car miles driven per year since 1970, Figure 4 shows that total emissions are still lower than they were at that time.

## Improvements in Air Quality

### Carbon Monoxide

Over 90 per cent of the carbon monoxide emitted in cities generally comes from motor vehicles. Because the affinity of haemoglobin in the blood is 200 times greater for carbon monoxide than for oxygen, carbon monoxide hinders oxygen transport from blood into tissues. Therefore, in the presence of carbon monoxide, more blood must be pumped to deliver the same amount of oxygen. Numerous studies in humans and animals have now demonstrated that those individuals with weak hearts are placed under additional strain by the presence of excess carbon monoxide in the blood (2, 3). In addition, foetuses, sickle cell anaemics and young children may also be particularly susceptible to even low levels of carbon monoxide.

Carbon monoxide air quality levels across the U.S.A. have improved dramatically over the last decade. According to the latest Environmental Protection Agency estimates, nationwide improvements have averaged about 5 per cent per year, giving an overall reduction of 33 per cent between 1975 and 1983 (4). Viewed in terms of the actual number of times the health based air quality standard was violated, the improvement has been even more dramatic—about an 87 per cent reduction.

Since virtually all the carbon monoxide in areas with dirty air is emitted by motor vehicles, this is the clearest evidence that the programme has been a resounding success.

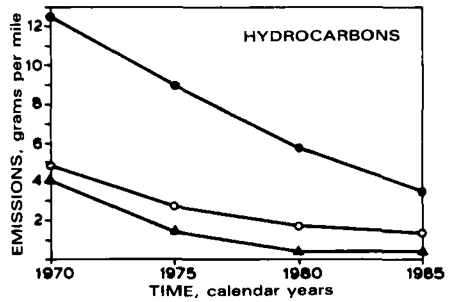



**Fig. 1 The fall in hydrocarbon emissions measured in grams per mile for new cars from 1970 to 1985, after the introduction of the Amendments to the Clean Air Act.**
- ▲ **emission standard for each model year**
- o **average actual emissions from the model year vehicles**
- • **emissions from the total population of automobiles during that time**

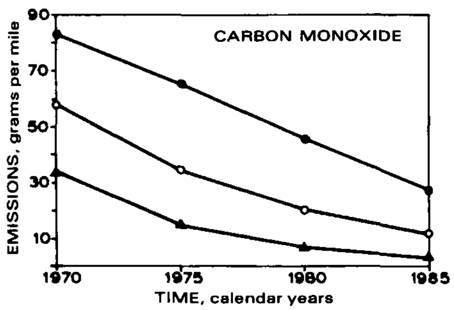



**Fig. 2 The fall in carbon monoxide emission, measured in grams per mile, between 1970 and 1985. The key is as in Figure 1**

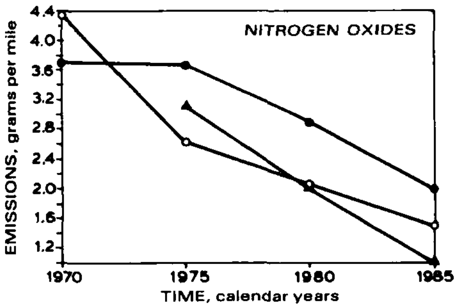



**Fig. 3 The fall in nitrogen oxide emissions, measured in grams per mile, between 1970 and 1985. The key is as in Figure 1**

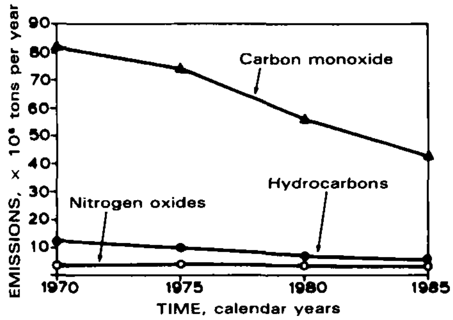



**Fig. 4 The total exhaust emissions between 1970 and 1985 show a considerable fall, even though the total number of vehicles has increased and the total number of miles driven has also increased during this time**

## Nitrogen Oxides

As a class of compounds, the oxides of nitrogen are involved in a large number of environmental problems that adversely affect human health and welfare. Nitrogen dioxide has been linked with increased susceptibility to respiratory infection, increased airway resistance in asthmatics, and decreased pulmonary function (5). Even short term exposure to nitrogen dioxide has resulted in a wide ranging group of respiratory problems in school children—coughs, runny noses and sore throats are among the most common—and increased sensitivity to bronchoconstrictors by asthmatics (6, 7).

Nitrogen oxides are only partially the result of motor vehicle emissions, averaging between 30 and 40 per cent in urban areas across the U.S.A. Overall in the U.S.A. nitrogen oxide emissions have only recently started to decline after many years of increases; indeed in some areas emissions are still increasing. Annual average nitrogen dioxide levels measured at 445 sites increased from 1975 to 1979, then decreased through 1983 (4). The 1983 composite average nitrogen dioxide level was 6 per cent lower than the 1975 level. The data indicate that air quality is better than it would have been in the absence of motor vehicle controls, but that overall gains are less than they could have been, due to the increased number of miles travelled and increased emissions from the many stationary sources that are significant emitters of nitrogen oxides. The control of nitrogen oxides emissions is important not only for the direct health benefits but also because of their key role in photochemical smog and the growing problem of acid rain. Evidence indicates that many lakes and forests have already been degraded by these problems (8, 9, 10, 11).

### Ozone

The most widespread air pollution problem in areas with temperate climates is ozone, one of the photochemical oxidants which results from the reaction of nitrogen oxides and hydrocarbons in the presence of sunlight. Motor vehicles are a major source of both of these precursor pollutants.

Adverse health consequences associated with exposure to elevated levels of ozone include eye irritation, cough and chest discomfort, headaches, upper respiratory illness, increased asthma attacks and reduced pulmonary function (12).

Numerous studies have demonstrated that photochemical pollutants seriously impair the growth of certain crops. For example, the Congressional Research Service (C.R.S.) of the U.S. Library of Congress found that, in the United States alone, "the short-run or immediate impacts of ozone are evident in annual crop yield decreases estimated at $1.9 to $4.3 billion" (13). In the longer term, C.R.S. points out that "ozone damage has resulted in disappearance of high yielding crops from localities and even from the genetic base". Other negative impacts include seed yield reduction of 10 to 22 per cent in field corn, up to 33 per cent reductions in wheat yields and from 24 to 50 per cent reductions in soybean yields. Timber volume may also be reduced significantly.

Ozone levels are the most difficult from which to draw general conclusions of relevance to the motor vehicle control programme,

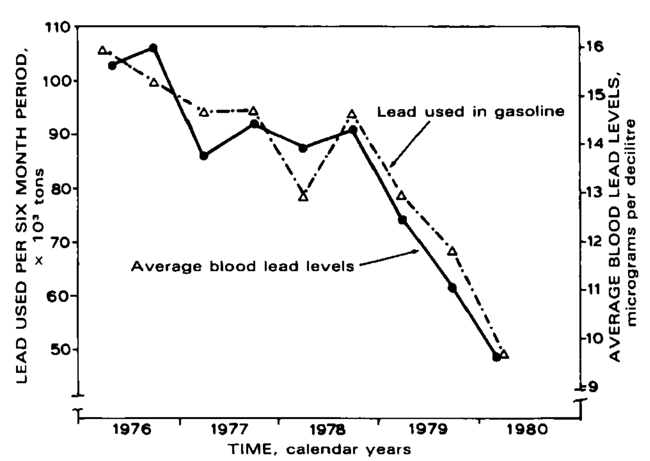



**Fig. 5 Between 1976 and 1980 the average level of lead in blood declined by approximately 36.7 per cent, which closely follows the reduced amount of lead used in the production of gasoline over that period**

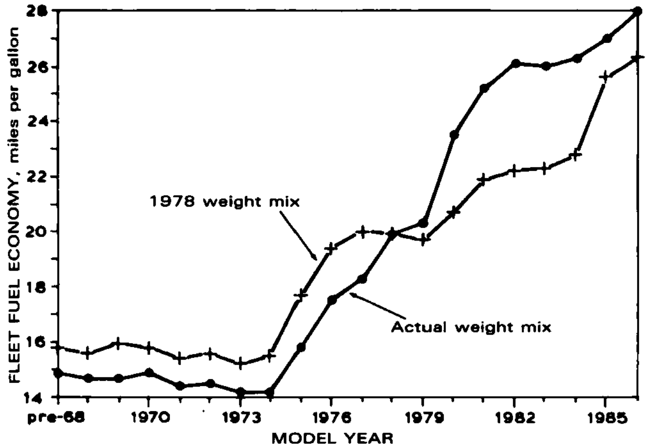



**Fig. 6 Improved emission standards have also produced improved fuel economy, from 14.9 mpg for the 1976 model year automobiles to 28.0 mpg for the 1986 model year vehicles**

because hydrocarbon and nitrogen oxides emissions (the pollutants which are transformed into ozone) come from so many sources in addition to motor vehicles, and because of the complex photochemistry involved. However, nationally recorded data show that comparable ozone values have decreased 8 per cent between 1975 and 1983 (4). As with carbon monoxide the improvement in the number of times the air quality standard was exceeded was even greater, about 37 per cent. Certainly the control of hydrocarbons and nitrogen oxides from motor vehicles has played a significant role in bringing about these ozone reductions.

### Lead

Since catalysts, the primary technology for lowering carbon monoxide, hydrocarbon and nitrogen oxide levels from vehicles, can be deactivated by the presence of poisoning compounds such as lead, the use of catalysts has required the removal from gasoline of the anti-knock agent tetra ethyl lead. This is also advantageous because of the serious adverse health effects which lead causes in children (14, 15, 16). Several studies have now shown that children with high levels of lead accumulated in their baby teeth experience more behavioural problems, lower IQs and decreased ability to concentrate (17).

Reducing the lead content of gasoline has been demonstrated to reduce significantly the health risks in urban areas of the U.S.A. For example, based on data collected in more than 60 cities by the Center for Disease Control, Figure 5 shows that the decline in mean blood lead levels, approximately 36.7 per cent from 1976 to 1980, closely parallels the reduction in the amount of lead used in the production of gasoline during the same period of time (18).

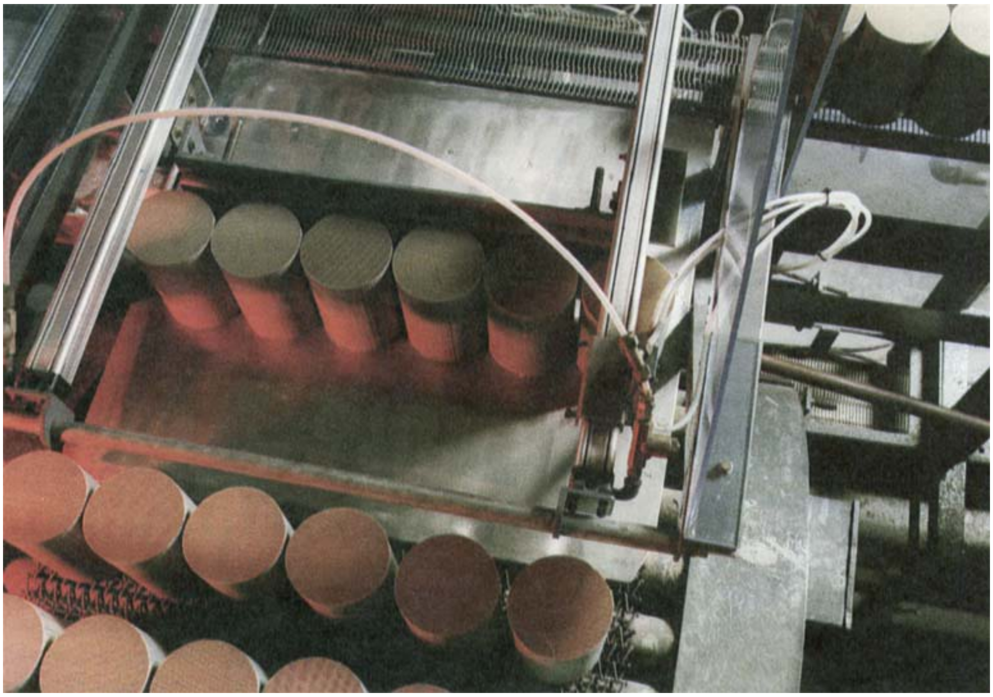
Ambient lead levels have also declined substantially; the composite maximum quarterly average of ambient lead levels, recorded at 138 sites across the country, decreased 67 per cent between 1975 and 1981 (4).

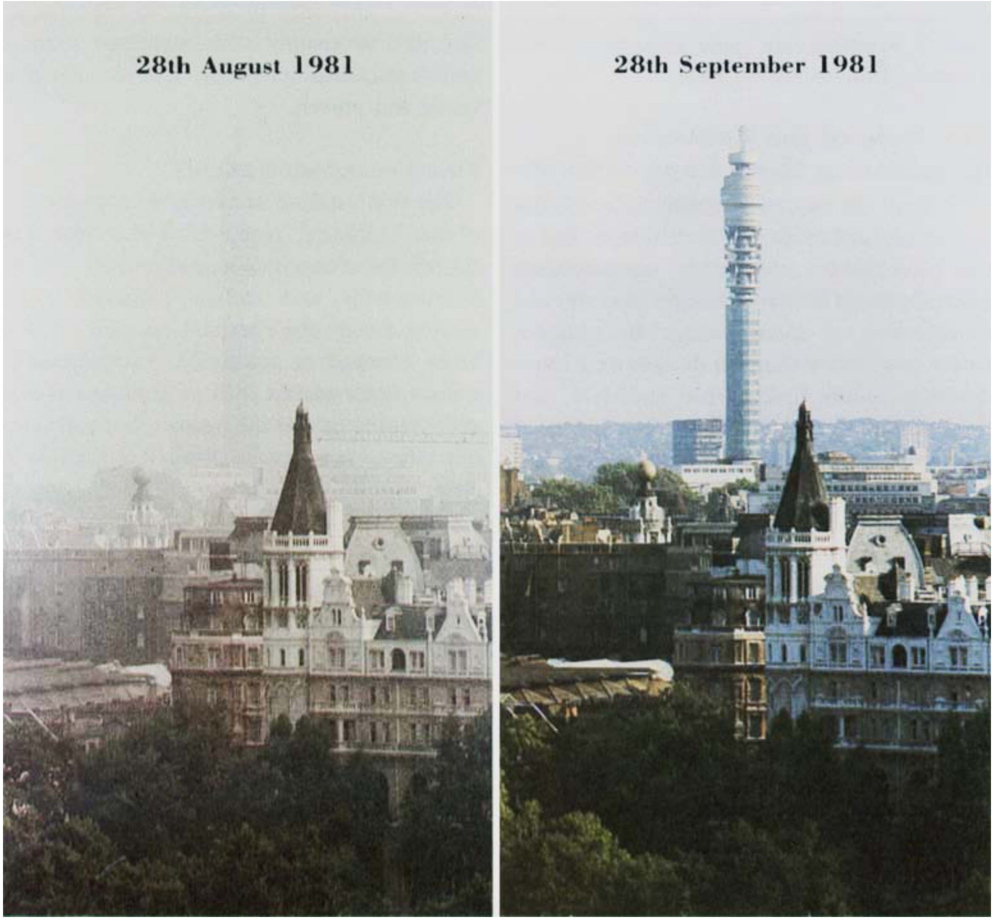
## Fuel Economy

Attainment of the emission standards has been accompanied by fuel economy improvements, from a sales weighted average of 14.9 miles per gallon (mpg) for 1967 model year automobiles to 28.0 mpg in 1986—an increase of 88 per cent (19). Even after correcting for vehicle weight reductions, the improvements compared to pre-controlled automobiles are still over 50 per cent.

The average fuel economy over the last decade, corrected to compensate for any weight shifts, is illustrated in Figure 6. The introduction of unleaded fuel and catalytic converters in 1975 contributed to very substantial gains in fuel economy. At a minimum, the data

Johnson Matthey is a world leader in automotive emission control catalyst technology and manufacture. To maintain this position an extensive development programme is continuing. This involves the use of the most up to date facilities, including scanning electron microscopy. Close liaison with customers and governmental authorities ensures that this work pays due regard to environmental, economic and technical considerations. In the U.S.A., Johnson Matthey is the largest manufacturer of autocatalysts with total production now exceeding 50 million units. Some of these have been exported to the Far East for both local use and for fitting to vehicles sold in the U.S.A. In Australia a recently opened factory satisfies almost all of local demand. European authorities in the main have been slower to act but European manufacturers exporting vehicles to the U.S.A. have responded to U.S. legislation. Indeed the Johnson Matthey factory at Royston has already produced more than a million units for one European customer. Ceramic monoliths are shown here prior to coating with platinum metals catalyst






**In addition to the U.S.A., Japan, Australia and South Korea are among the countries striving to reduce automobile emissions. In Europe also there is now a growing awareness of air pollution and the damage resulting from it. This pair of photographs of the "Post Office Tower" in London illustrate the undesirable presence of photochemical smog. Furthermore evidence is accumulating which suggests that "acid rain" is having a detrimental effect on coniferous woodlands such as the German Black Forest, part of which is shown here. It seems probable that emissions from vehicles are major contributors to this form of environmental pollution. The governments of the Federal Republic of Germany, Austria, Switzerland and the Netherlands are encouraging the sale of catalyst-equipped "clean" cars through fiscal incentives**

now available demonstrate that tight emissions control standards are quite compatible with substantial fuel economy gains.

## The Role of the Converter in Achieving these Improvements

To meet the relatively lenient hydrocarbons and carbon monoxide standards that applied in the early 1970s, automobile manufacturers generally relied on leaner air-fuel mixtures and modification of spark timing. In addition, newer combustion chamber designs were introduced to reduce hydrocarbon emissions, and with faster flames to limit the increased nitrogen oxides. Even when hydrocarbons and carbon monoxide standards were tightened, the engine modification approach continued to predominate, with the addition of certain new modifications such as transmission controlled spark timing and anti-dieseling throttle control. Attainment of initial hydrocarbon and carbon monoxide standards with limitations on nitrogen oxides increases was generally possible without significant fuel consumption penalties. However, as emissions standards were tightened (especially in 1973 and 1974) it became increasingly difficult to achieve low levels of carbon monoxide, hydrocarbons and nitrogen oxides without unacceptable compromises in performance or fuel economy. As a result there was a fundamental shift in the technology to the catalytic converter. Johnson Matthey was in the forefront of this development.

Starting with 1975 model year automobiles, catalysts were placed on more than 80 per cent of all new automobiles in the U.S.A. Since 1981, they have been placed on 100 per cent of the new gasoline-fuelled automobiles. Initial systems in 1975 contained primarily oxidation catalysts but with time the emphasis has gradually shifted to predominantly three-way systems.

This model year, 1986, is the twelfth year that emissions control systems featuring catalytic converters have appeared in production quantities in light-duty vehicles. After an initial period of uncertainty they have gained broad acceptance in the United States and in Japan as the only practical way for manufacturers to comply with mandated exhaust emissions control standards. This technology is tested and proven.

### First Generation Catalysts

The first catalytic converter introduced was of the "oxidising" type, which when placed in the tailpipe of an automobile effectively reduces hydrocarbons and carbon monoxide. The catalyst fosters the chemical reaction without being changed or consumed. In this case it utilises noble metals such as platinum and/or palladium to oxidise the hydrocarbons and carbon monoxide molecules into carbon dioxide or water vapour.

### Three-Way Catalysts

Three-way catalysts, so called because of their ability to lower hydrocarbons, carbon monoxide and nitrogen oxide levels simultaneously, were first introduced in the U.S.A. in 1977 by Volvo and have subsequently become widely used as the U.S.A. nitrogen oxide standard has been made more stringent. For these catalysts to work effectively, it is necessary to control air-fuel mixtures much more precisely than is needed for oxidation catalyst systems. As a result, three-way catalyst systems have indirectly fostered improved air-fuel management systems such as advanced carburettors and even throttle body fuel injection systems, as well as electronic controls.

To date, approximately 100 million converters are in use in vehicles in the U.S.A. spread across virtually every make and size of light-duty vehicle. After exposure to a wide

**Table I**
**Aldehyde Emissions**

| Vehicle type | Emissions, grams per mile |
|---|---|
| Average of 10 non-catalyst gasoline cars | 0.141 |
| Average of 3 catalyst gasoline cars | 0.023 |

range of driving conditions, field performance clearly shows that converters have sufficient integrity to withstand rigorous use. Whether exposed to extremes of temperature and humidity, high or low altitude, heavy or light loads and even off-road terrain, the evidence shows them to have excellent durability.

## Additional Benefits Resulting from the Use of Catalysts

This article has already outlined several of the advantages resulting from the use of the catalytic converters. First and foremost, of course, is the dramatic reduction in both carbon monoxide and hydrocarbons which can result; nitrogen oxides can also be dramatically reduced if a three-way catalyst is used. It has also been demonstrated that the use of the catalyst encourages the car's engine to be tuned to optimise fuel economy and performance, in the knowledge that the catalyst will clean up the residual pollution. An additional advantage is that changes made to the engine in an effort to optimise the effectiveness of the catalyst, for example by more precise air-fuel management and electronic ignition systems, also tend to improve vehicle fuel economy and performance. However, the catalyst has several additional advantages which are now summarised (20, 21).

### Aldehydes

These are the most prevalent oxygenated organic species in gasoline engine exhaust, and they tend to be highly photochemically reactive and to contribute directly to eye irritation. The available data given in Table I show that these compounds are also effectively reduced by catalysts, along with hydrocarbons. Note also that one particular aldehyde, formaldehyde, has been found to be an animal carcinogen.

**Table II**

**Benzo(a)pyrene Emissions**

| Vehicle type | Emissions, micrograms per mile |
|---|---|
| Pre-emissions control | 12.04 |
| 1968 emissions controlled | 2.77 |
| 1970 emissions controlled | 1.62 |
| Catalyst equipped | 0.08 |

### Reactive Hydrocarbons

The current standard for exhaust hydrocarbon emissions, 0.41 grams per mile, reflects a 90 per cent reduction in total hydrocarbons from 1970 automobiles. However, since catalytic converters tend to selectively oxidise the more reactive hydrocarbons more easily than methane, in excess of 90 per cent of the hydrocarbon species which participate in the photochemical reactions leading to smog will be reduced by catalysts. Whereas a non-methane hydrocarbon standard of 0.39 reflects a 90 per cent reduction in reactive hydrocarbons, catalyst-equipped vehicles meeting a 0.41 total hydrocarbon standard will actually emit about 0.26 to 0.29 grams per mile of non-methane hydrocarbons, reflecting a reduction of about 92-93 per cent in the reactive hydrocarbons.

### Polynuclear Aromatics

Emissions of this class of hydrocarbons are of particular interest because of the well established direct carcinogenic effects of certain polynuclear aromatic compounds which have been detected in vehicle exhaust. For example, benzene is emitted in sufficient quantities from gasoline powered automobiles not fitted with catalysts and has been strongly linked to leukaemia. Most notable among the polynuclear aromatics are benzo(a)pyrene (BaP), a five ring aromatic compound that has been shown to be an animal carcinogen.

BaP emission data from passenger automobiles with various types of control technology are given in Table II which shows that polynuclear aromatic emissions from gasoline powered automobiles can be reduced substantially by controls designed to reduce hydrocarbons and carbon monoxide, but that catalytic converters can almost eliminate them. In fact, the catalyst equipped vehicle reduced BaP by over 99 per cent from pre-controlled levels, and by about 96 per cent from 1970 levels with first generation emission controls. There is every reason to conclude that the catalyst has the same impact on other multi-ring aromatics which are likely to be in gasoline vehicle exhaust. For example, a recent study of a gasoline powered programmed combustion engine measured various polycyclic aromatic hydrocarbons both with and without a catalyst. Although these emissions were from an experimental laboratory engine, it is likely that a simple spark ignition gasoline engine emits similar compounds. The data, given in Table III, show that polynuclear aromatic hydrocarbons are removed by catalysts and in most cases the removal rate is substantial.

### Lead Free Gasoline

In addition to reducing health risks and allowing the use of catalytic converters to control emissions, the elimination of lead from gasoline has had several additional benefits. When lead is used in gasoline, lead scavengers such as ethylene dibromide and ethylene dichloride are required to reduce combustion chamber deposits (22). These scavengers are highly corrosive and reactive and their elimination reduces the motorists' costs for servicing and replacing spark plugs, silencer mufflers and other automobile hardware exposed to gasoline and its combustion products. As a rough rule of thumb, spark plug change intervals are roughly doubled by the use of unleaded gasoline, and at least one exhaust system and muffler replacement is eliminated. The lead free gasoline has also been linked to a cost advantage regarding carburettor servicing but this has been more difficult to quantify.

Another significant advantage associated with the use of lead free gasoline is the lengthened oil change interval. The use of unleaded fuel has been demonstrated to reduce engine rusting and ring wear significantly and to reduce by a lesser degree sludge and varnish deposits and cam and lifter wear. As a result, oil change intervals on automobiles using unleaded fuel are at least twice as long as has traditionally been the case. This is significant not only because of the reduced cost to the motorist but also because of the oil savings over the life of the vehicle and the reduction of the potential pollution problem resulting from the disposal of used oil. Experience has shown that in the U.S.A. significant quantities of used oil are disposed of in ecologically unacceptable ways, such as dumping it on the ground. Also, evidence indicates that used motor oil contains human carcinogens.

## Conclusions

As a result of stringent emission control legislation, automobiles in the United States of America are substantially cleaner today than they were in the past. Emissions of carbon monoxide, hydrocarbons and nitrogen oxides

**Table III**
**Polycyclic Aromatic Hydrocarbon Emissions from a Programmed Combustion Engine**

| Polycyclic aromatic hydrocarbon | Emissions, micrograms per mile | |
|---|---|---|
| | Without catalyst | With catalyst |
| phenanthrene | 1.85 | 0.16 |
| anthracene | 0.61 | 0.04 |
| fluoranthrene | 2.27 | 0.23 |
| phrene | 2.91 | 1.50 |
| perylene | 1.21 | 0.40 |
| benzo(a)pyrene | 0.94 | 0.17 |
| benzo(e)pyrene | 2.76 | 0.41 |
| dibenzopyrenes | 0.28 | 0.23 |
| coronene | 0.41 | 0.27 |

per mile driven have been reduced by 86, 84 and 56 per cent, respectively. Further, reductions in gasoline lead content have resulted in parallel reductions in the levels of lead in the blood of children. These improvements have occurred at the same time as fuel economy has increased very significantly; in fact, the technological developments fostered by tight emissions standards are partially responsible for the improved fuel economy.

Platinum metals catalytic technology has emerged as the most desirable means for achieving the joint goals of low emissions and good fuel economy. This technology has also resulted in substantial improvements in other unregulated pollutants.

Certainly many serious and difficult air pollution problems remain which will need to be addressed. Some are associated with inappropriate fuelling of catalyst equipped automobiles or the tampering and misadjustment of emission control systems. Truck emissions are an increasing worry and while some progress is imminent for hydrocarbons and carbon monoxide, nitrogen oxide emissions are still much too high. Finally, particulate emissions from diesel automobiles and trucks are an increasingly serious health concern, as well as a source of many other environmental problems. However, as we tackle these difficult problems it is heartening to look back on what has been accomplished and the part played by the platinum group metals. The success of yesterday can serve as a model for the future.

## References


1 Mobile 3, Mobile Source Emissions Model, U.S. Environmental Protection Agency, Office of Mobile Source Air Pollution Control, 1985

2 "Carbon Monoxide", National Research Council, National Academy of Sciences, Subcommittee on Carbon Monoxide, September 1977

3 "Revisions to the National Ambient Air Quality Standards for Carbon Monoxide", Draft, U.S. Environmental Protection Agency, April 1982

4 "National Air Quality and Emissions Trends Report, 1983", U.S. Environmental Protection Agency, April 1985

5 "Air Quality Criteria for Nitrogen Oxides", Draft, U.S. Environmental Protection Agency, June 1980

6 R. A. Mostardi et al, "The University of Akron Study on Air Pollution and Human Health Effects", *Arch. Environ. Health*, 1981, **36**, (5), 243, 250

7 J. Orehek, J. P. Massari, P. Gayrard, C. Grimaud and J. Charpin, "Effect of Short-Term, Low-Level Nitrogen Dioxide Exposure on Bronchial Sensitivity of Asthmatic Patients", *J. Clin. Invest.*, 1976, 57, 301

8 "Acid Rain and Transported Air Pollutants, Implications for Public Policy", U.S. Congress, Office of Technology Assessment, June 1984

9 "Acidification Today and Tomorrow", Swedish Study Prepared for the 1982 Stockholm Conference on the Acidification of the Environment, Ministry of Agriculture, Environment '82 Committee, 1982

10 "Acid Deposition, Atmospheric Processes in Eastern North America", National Research Council, National Academy of Sciences, 1983

11 Stockholm Conference on Acidification of the Environment, Conclusions and Recommendations, 1982

12 "Air Quality Criteria for Ozone and Other Photochemical Oxidants", U.S. Environmental Protection Agency, April 1978

13 J. P. Biniek, "Air Pollutant Impacts on Agriculture and Forestry", Congressional Research Service, The Library of Congress, Spring 1982

14 "Lead in Petrol and Vehicle Emissions", House of Lords Select Committee on the European Communities, 26 February 1985

15 "Lead in the Human Environment", National Research Council, National Academy of Sciences, Washington, D.C., 1980

16 United States Court of Appeals, No. 82–2282, Small Refiner Lead Phase-Down Task Force et al v. U.S. Environmental Protection Agency, 22 April 1983

17 H. L. Needleman et al, "Deficits in Psychologic and Classroom Performance of Children with Elevated Dentine Lead Levels", *New Engl. J. Med.*, 1979, **300**, (13), 689

18 J. L. Annest et al, "Chronological Trend in Blood Lead Levels between 1976 and 1980", *New Engl. J. Med.*, 1983, **308**, (23), 1374

19 Heavenrich et al, "Light Duty Automotive Trends through 1986", S.A.E. Paper No. 860366, 1986

20 M. W. Jackson, "Effect of Catalytic Emission Control on Exhaust Hydrocarbon Composition and Reactivity", S.A.E. Paper No. 780624, 1978

21 F. M. Black and L. E. High, "Automotive Hydrocarbon Emission Patterns in the Measurement of Nonmethane Hydrocarbon Emission Rates", S.A.E. Paper No. 770144, 1977

22 J. E. Sigsby et al, "Automotive Emissions of Ethylene Dibromide", S.A.E. Paper No. 820786, 1982