# FUEL REFORMULATION : A MEAN TO IMPROVE AIR QUALITY IN BANGKOK

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## 1. Air Pollution Problems from Motor Vehicles in Bangkok

BANGKOK, the capital and principal city of Thailand, is one of the cities in the world with serious air pollution problems which are accounted for mostly by the transport sector. Air pollution problems in Bangkok are largely due to extreme traffic congestion coupled with only minimal controls on motor vehicle emissions. The resulting air pollutant concentrations at street level along the major roads have reached hazardous levels. Fortunately enough, due to favorable geography and meteorology, Bangkok however does not suffer significantly from regional-scale air pollution.

The recent astounding economic growth and prosperity has indeed exacerbated air pollution problems in Bangkok through the expansion that has occurred in population number and road transport. The growing need to transport goods and people has resulted in an unprecedented increase in the number of motor vehicles of every size and variety to meet the demand for both private and public transportation. Many new vehicles are added each year to the already high vehicle population and to the inadequate street and roadway network of Bangkok. Consequently, traffic congestion and transport-related air pollution in Bangkok have grown and imposed significant costs through their impacts on health and productivity, and continue to worsen.

The number of motor vehicles registered in Bangkok has soared from 600,000 in 1980 to 2.7 million in 1993 which accounted for about a quarter of all motor vehicles registered in Thailand. In 1993 alone, 400,000 new vehicles were added to the Bangkok' s fleet representing an increase of 17% from 1992. Particularly striking has been that 46% of all vehicles in Bangkok are motorcycles of which more than 90% have two-stroke engines, the worst offenders for suspended particulate matter and hydrocarbon emissions. Per capita vehicle ownership in Bangkok is estimated at approximately 380 vehicles per thousand residents.

Moreover, traffic congestion in Bangkok is worse also because of the low amount of land devoted to roads and because of the development concentrated along the road networks without any proper planning control. The road space as a share of total area in Bangkok is only 11 percent, which is substantially lower than international standards of between 20% to 25% In spite of attempts to expand the road networks, it has been unable to keep pace with the demand and congestion continues to worsen. Land expropriation in Bangkok for road network expansion becomes more difficult and more expensive.

Traffic congestion is also associated with increased emissions of carbon monoxide, hydrocarbons, and particulate matter. This is due both to longer trip times and the higher emissions associated with vehicle slow speed and the need for more frequent deceleration, stopping, and acceleration. It was estimated that travel speeds during peak hour in 1991 for the inner and middle areas of Bangkok are as low as 10.6 km/hr and 17.5 km/hr, respectively. The estimated minimum travel speed in the inner area will be slightly lower to 9 km/hr whereas the traffic congestion in the middle area will be much worse with the minimum travel speed of only 7.8 km/hr.

USAID' s study in 1990 attempting to rank environmental health risks of 5.5 million people living in Bangkok estimated that 270,000 people are at moderate risk for health effects associated with carbon monoxide (angina to persons with chronic cardiovascular disease) and 1.3 million people at mild risk (inability to concentrate and headaches for persons in general population).

Another study in 1993 compared the prevalence of respiratory symptoms and diseases and pulmonary parameters between traffic policemen and non-traffic policemen in Bangkok. Traffic policeman is the group of population who is daily exposed to and affected by transport-related air pollutants at least 8 hours a day. The study showed higher reported respiratory symptoms and reduced ventilation flow rate in the traffic policemen which may indicate that small airways in the lungs are narrowed by air pollutants.

**2. Current Air Quality in Bangkok**

Results of air quality monitoring over the past 11 years indicate that the air pollutants of greatest concern in Bangkok are suspended particulate matter (SPM), especially respirable particulate matter (PM 10), carbon monoxide (CO), and lead, respectively. They are accounted for mostly by the transport sector. The World Bank's recently-completed Economic Report on Urban Environmental Problems in Thailand in 1993 estimated emissions in 1991 from transport sector of these air pollutants to be 76, 1,065, and 0.62 thousand tons per year, respectively. The report also concluded that air pollution in Bangkok due to high concentrations of suspended particulate matter is among the highest priority problems. The principal concern with these air pollutants is along the major roads in Bangkok where pollutant concentrations are high enough to result in significant adverse health impacts on the population.

**2.1 Suspended Particulate Matter (SPM)** Current levels of SPM in Bangkok's air, especially along roads which all have very congested traffic and produce start-stops cycles with very low speed, far exceed Thailand's primary ambient air quality standard for SPM. In 1994, curbside 24-hour average concentrations of suspended particulate matter exceed the standard of 0.33 $mg/m^3$ at all stations with the mean of 0.35 $mg/m^3$ and the range of 0.05 to 1.13 $mg/m^3$. There were 138 days out of 261 measurement days or approximately 53% occurrence that the concentrations exceeded the standard. It is found that 40% by weight of SPM in Bangkok are from diesel fuelled vehicles, 40% are road dust, and the rest are sea salt particles and from industries. In addition, 60% by weight of SPM are respirable having sizes of less than 10 microns (PM 10).

**2.2 Carbon Monoxide (CO)** Similarly, curbside 1-hour and 8-hour average concentrations of carbon monoxide also exceed the standards of 35 and 10 $mg/m^3$, respectively. As high concentration as 45 $mg/m^3$ for 1-hour average concentration and 30 $mg/m^3$ for 8-hour average concentration were recorded with the mean of 5.21 and 5.12 $mg/m^3$, respectively. Nevertheless, carbon monoxide has been observed to be on the decline or stable since 1992 in the congested streets for the 1-hour average concentrations, but the 8-hour average concentrations have not shown a similar declining trend. This may indicate that for the peak hour the introduction of new cars and emission control technology together with better fuel quality may lessen the air quality problem as the traffic volume is the same (traffic has reached saturation level), however the peak hours may be longer, thus the longer averaging time (8-hour) may produce the stable or increasing trend. For comparison, 319 out of 5,217 measurements (about 6% occurrence) of 8-hour average concentration in 1994 exceeded the standard while there are only 4 out of 5,509 measurements (less than 0.1% occurrence) of 1-hour average concentration.

**2.3 Lead (Pb)** Lead was observed to be also reduced in recent years due mainly to the reduction of lead content of leaded gasoline and the use of unleaded gasoline. The present range of 24-hour average concentrations of lead at the curbside stations is usually less than 1 ug/m$^3$ with the mean of 0.26 ug/m$^3$ compared to the standard of 10 ug/m$^3$.

### 3. Government Measures to Reduce Air Pollution from Motor Vehicles

The actual cause of today serious air pollution problems in Bangkok is that the past six Five-year National Economic and Social Development Plans of the country which ran from 1961 to 1991 emphasized only economic growth and viewed the country's natural resource base largely in terms of its economic potential. As a result, today Thailand' s economy is flourishing with increasing prosperity of the Thai people. On the other hand, air pollution associated with these improvements is lowering the air quality and thus the quality of life.

The analyses made by the World Bank indicates that if ambient concentrations of suspended particulate matter and lead in Bangkok are reduced by 20% from current levels, the mid-point estimates of the annual health benefits from less sickness and lower mortality would be between US$1 billion and US$1.6 billion and between US$300 million and US$1.5 billion, respectively. Another study assigned various monetary values to the estimated health risks and estimated and economic benefit of US$10.7 million annually from carbon monoxide reduction in Bangkok.

The public and the government are voicing their serious concern about the increasing trend of environmental pollution problems. Thailand' s current Seventh Plan from 1992 to 1996 has thus moved towards a sustainable economic growth and promoted development while enhancing the quality of the environment and natural resource base. A high priority has been placed on improving air quality. Definite targets have been set to control the emissions of carbon monoxide, lead and sulfur dioxide from transport sector in 1996 not to exceed 750,000, 300 and 50,000 tons from the estimated emissions in 1990 of 950,000, 1030 and 100,000 tons, respectively.

To achieve the targets, a concerted cooperative effort is being made by the government, industries, the public, and non-governmental organizations to restore the quality of the air in Bangkok. A number of measures have been adopted to mitigate air pollution problems, particularly those caused by the transport sector. They are aimed not only at exhaust gas emission controls but also at the improvement of fuel quality and engine specification, implementation of in-use vehicle inspection and maintenance program, public transport improvement through mass transit systems, and the improvement of traffic condition through better traffic management. Among others, specific measures directed toward reducing vehicle emissions include:

- Introduction of unleaded gasoline in May 1991 at prices below that of leaded gasoline,
- As of January 1, 1992, the maximum allowable lead in leaded gasoline was reduced from 0.4 to 0.15 grams per liter.
- Phasing out regular leaded gasoline as of August 1994,

- Plan to phase out premium leaded gasoline in 1996,
- Additional gasoline reformulation also includes benzene, aromatic compounds and oxygen content,
- Reduction of the sulfur content of diesel fuel from 1.0 to 0.5 percent as of April 1992 in the Bangkok Metropolitan Area and after September 1993 throughout the whole country, further reduction to 0.25 and 0.05 percent will be effective for the whole country in January 1, 1996 and January 1, 2000, respectively,
- Reduction of the 90% distillation temperature of diesel fuel from 370 degrees celcius to 357 degrees as of April 1992 in the Bangkok Metropolitan Area and after September 1992 throughout the whole country,
- Requirement for all new gasoline-engine cars with engines larger than 1600 cc to install catalytic converters after January 1, 1993 and for all cars after September 1, 1993; European Union standards 91/441/EEC will be enforced in 1995,
- European Union standards ECE R40-00 for motorcycles were enforced in August 1993 and followed soon afterward by ECE R40-01; the third step standards for CO and HC of 13 and 5 gm/km, respectively, will be phased-in starting from July 1995,
- European Union standards ECE R 83(C) for light duty diesel engine vehicles are now in effect and will be followed soon afterward by 91/441/EEC; and 93/59/EEC for light commercial diesel engine vehicles will be enforced soon,
- European Union standards ECE R49-01 for heavy duty diesel engine vehicles are now in effect and will be followed by 91/542(A)/EEC (or Euro I) and 91/542(B)/EEC (or Euro II) by January 1, 1996 and January 1, 2000, respectively,
- Taxis and Tuk-Tuks have already been largely converted to operate on LPG,
- All in-use buses and trucks are subjected to inspection during annual registration renewals; only passenger vehicles being used for ten or more years and motorcycles being used for seven or more years are subjected to an annual after October 1994 while the newer ones will be subjected to inspection at different time periods; licenses have been given to private inspection center to carry out the inspection.
- Three mass transit systems, of which two are electrically-powered skytrains and one is elevated trains, are under construction in Bangkok.

### 4. Impacts of Fuel Reformulation on Air Quality in Bangkok

Like many other megacities in the world, air pollution problem in Bangkok is associated largely with the use of fuels in the transport sector. Types and amount of air pollutants emitted are thus related closely to the fuel quality, or in other words, what and how much are contained in the fuel. Better fuel quality means less pollution being produced.

In 1989, Thailand has started examining petroleum fuel specifications with the aim of reducing transport emissions as one of several measures to improve air quality in Bangkok and in other selected areas where there is serious non-attainment of national ambient air quality standards. Since then, gasoline and diesel fuels used in Thailand have undergone reformulation several times which have resulted in drastic improvement in air quality in Bangkok, especially for lead.

**4.1 Automotive Gasoline Reformulation** The major emissions of concern from gasoline fuelled vehicles are lead, carbon monoxide, unburned hydrocarbon, benzene, and other aromatic emissions which have carcinogenic effects in humans. Gasoline compositional changes which can have a major impact on emissions of these pollutants include the complete phasing out of lead, increasing the volatility, specifying a minimum combined oxygen content, and reduced aromatic content including benzene. Such fuel modifications can if carefully introduced substantially improve the environmental impacts of gasoline.

**4.1.1 Lead Content**

Lead in gasoline has been gradual reduced, as indicated below, both to reduce lead emissions and to facilitate the use of pollution control technologies such as catalytic converter. Methyl Tertiary Butyl Ether (MTBE) is normally used to boot up the octane of the gasoline replacing lead. Bangkok will soon become one of the lead free countries. Complete phasing out of lead is planned by the Government for as early as January 1, 1996.

| YEAR | Phasing Out of Lead |
|---|---|
| Before 1984 | 0.84 gm/liter leaded gasoline |
| 1984 | 0.45 gm/liter leaded gasoline |
| 1989 | 0.40 gm/liter leaded gasoline |
| 1991 | Premium ULG is available |
| 1992 | 0.15 gm/liter leaded gasoline |
| 1994 | Complete phase out of regular leaded gasoline |
| 1996 | Complete phase out of premium leaded gasoline |

Since lead in the urban air practically comes from combustion of leaded gasoline in gasoline fuelled vehicles, phasing out of lead in the gasoline has substantially reduced emissions of lead in to the air. Consequently, ambient lead concentrations in the congested streets and in general areas of Bangkok have been observed to be on the decline since 1990 coinciding with the phasing out of lead from the gasoline, as shown in Figure 1 and 2, respectively.

**4.1.2 Oxygen Content**

Although catalytic converters will dramaticlly reduce both carbon monoxide and hydrocarbon emissions from new gasoline fuelled vehicles after 1993, there are still a very large stock of in-use uncontrolled vehicles (more than 1 million uncontrolled passenger gasoline fuelled vehicles and more than 1 million motorcycles) on the roads in Bangkok for may be the next 10-15 years. Having no exhaust aftertreatment, not designed to meet any emission standards, operating with fairly rich air/fuel ratio mainly at idle or very low speeds as is typical in Bangkok, they have exceptionally high carbon monoxide emissions and to a lesser extent unburned hydrocarbons.

To primarily reduce emissions from these in-use uncontrolled vehicles, oxygenated compounds such as MTBE and ethanol of not less than 5.5% but not more than 10% by volume has been incorporated into the premium gasoline since 1993 to achieve combined oxygen level of between 1% and 2% by weight. Combined oxygen has the effect of leaning the air/fuel ratio of the engine and thus lowers the emissions of carbon monoxide and unburned hydrocarbon without making any mechanical adjustment.

As indicated earlier, carbon monoxide has been observed to be on the decline or stable since 1992 in the congested streets and general areas of Bangkok for the 1-hour average concentrations as shown in Figure 3 and 4, respectively. This seems to contradict with the increasing numbers of vehicle population in Bangkok, an increase of more than 400,000 vehicles (including motorcycles) within 2 years (1993 and 1994). It is felt that the decline is, to some extent, due to oxygenated compounds incorporate into the premium gasoline. The effect of oxygenated compounds on the ambient hydrocarbon levels has not been investigated.

#### 4.1.3 Benzene and Aromatics Content

The aromatics, including benzene, content of gasoline directly affects the amount of air toxics emissions in the exhaust gases, although the emissions will be lower from a catalyst equipped car. The most concern is benzene which is known to have carcinogenic effects in humans and is found in exhaust gases not only directly from benzene in the gasoline but also from the thermal dealkylation of higher aromatics such as toluene and xylenes in the combustion process.

In order to reduce the emissions of air toxics, benzene content in both regular and premium gasoline was limited to not more than 5.0% by volume in July 1991 and has been further reduced to not more than 3.5% by volume in January 1992. Additionally, aromatics content has been regulated to not more than 50% by volume in January 1994 and is scheduled to be reduced to not more than 35% by volume in January 2000.

**4.2 Automotive Diesel Fuel Reformulation** The major emissions of concern from diesel fuelled vehicles are suspended particulate matter including respirable particulate matter, black smoke, unburned hydrocarbon, nitrogen oxides, and sulfur oxides. The extent and nature of black smoke generated in diesel engines is determined dominantly by engine design and operating factors as well as fuel characteristics. Since the principal air pollution problem in Bangkok is particulate matter, diesel characteristic changes which can have a major impact on emissions of particulate matter including black smoke include reducing the maximum allowable 90% volume distilled temperature and the maximum allowable sulfur content.

#### 4.2.1 90% Volume Distilled Temperature

Diesel fuel with a very high 90% distilled temperature contributes to both carbonaceous soot and soluble organic materials in the smoke especially in stop and go operating conditions typical of Bangkok. The government took an initiation in 1992 reducing the maximum allowable 90% volume distilled temperature from 370 to 357 degree celcius. Buses operated in Bangkok area are currently required to use diesel fuel with 90% distilled temperature of not more than 338 degree celcius. Discussion is being made to regulate 338 degree celcius for the whole country.

Lowering the 90% distilled temperature of diesel fuel probably contribute, to some extent, to the decreasing trend of ambient suspended particulate matter in Bangkok observed in the recent years as shown in Figure 5 and 6, similar to that of carbon monoxide.

#### 4.2.2 Sulfur Content

Reduction of sulfur content of diesel fuel will be beneficial not only to reduce emissions of sulfur oxides but also to reduce emissions of small diesel particulate matter. The maximum allowable sulfur content of diesel fuel was reduced from 1% to 0.5% by weight in September 1993. Further reduction to 0.25% and 0.05% will be enforeced in January 1996 and January 2000, respectively.

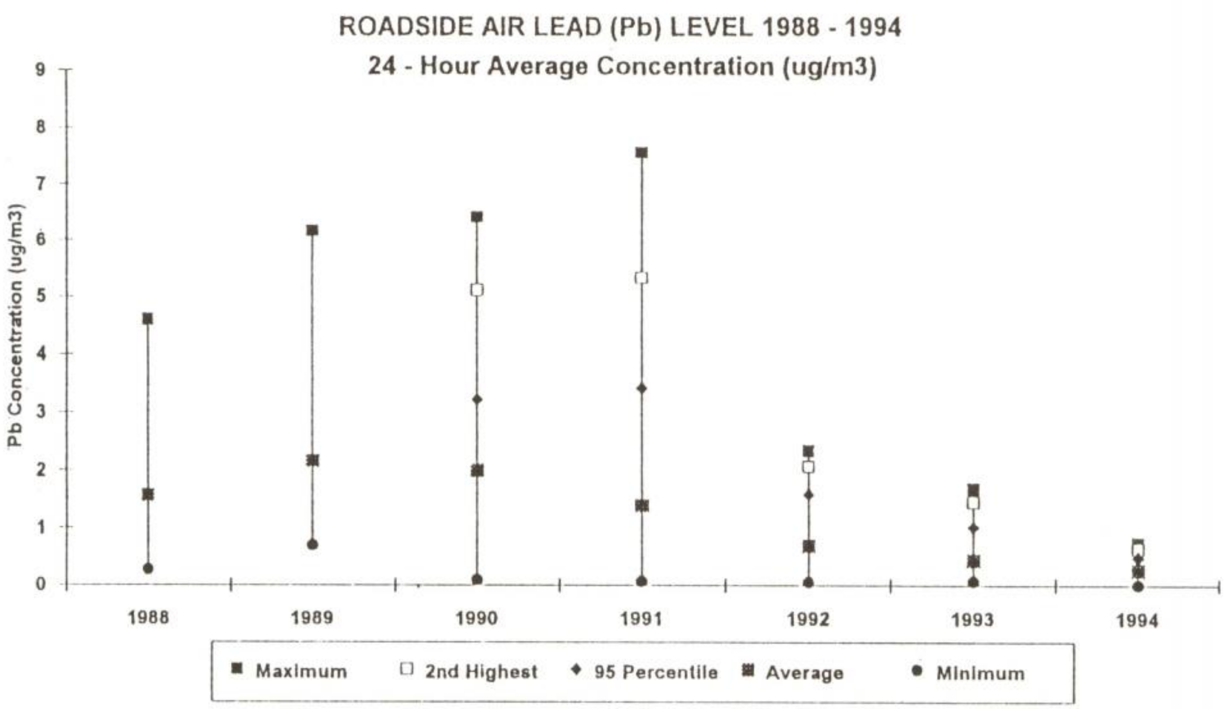


**Figure 1**

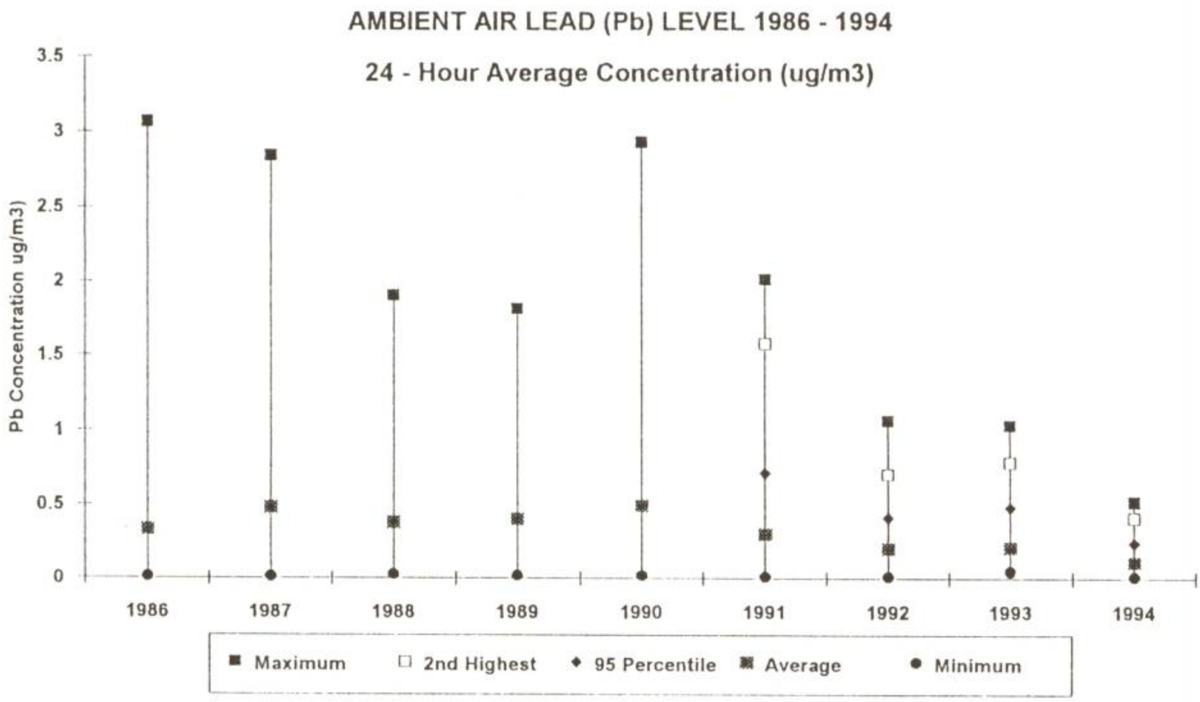


**Figure 2**

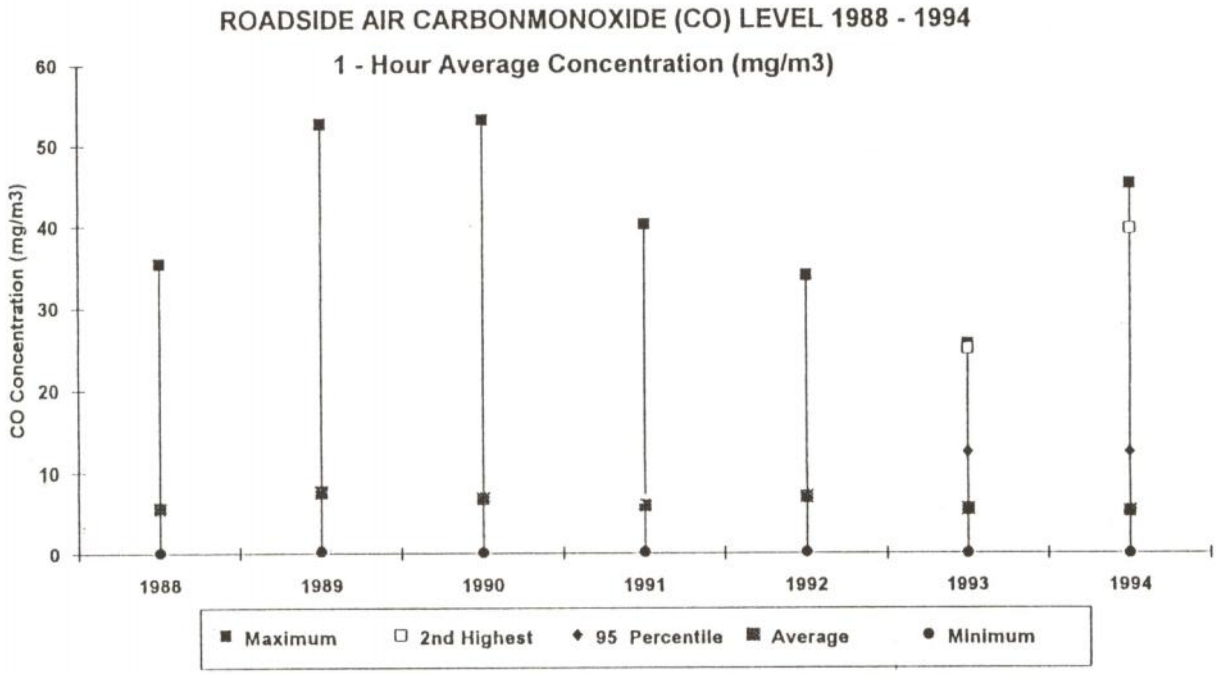


**Figure 3**

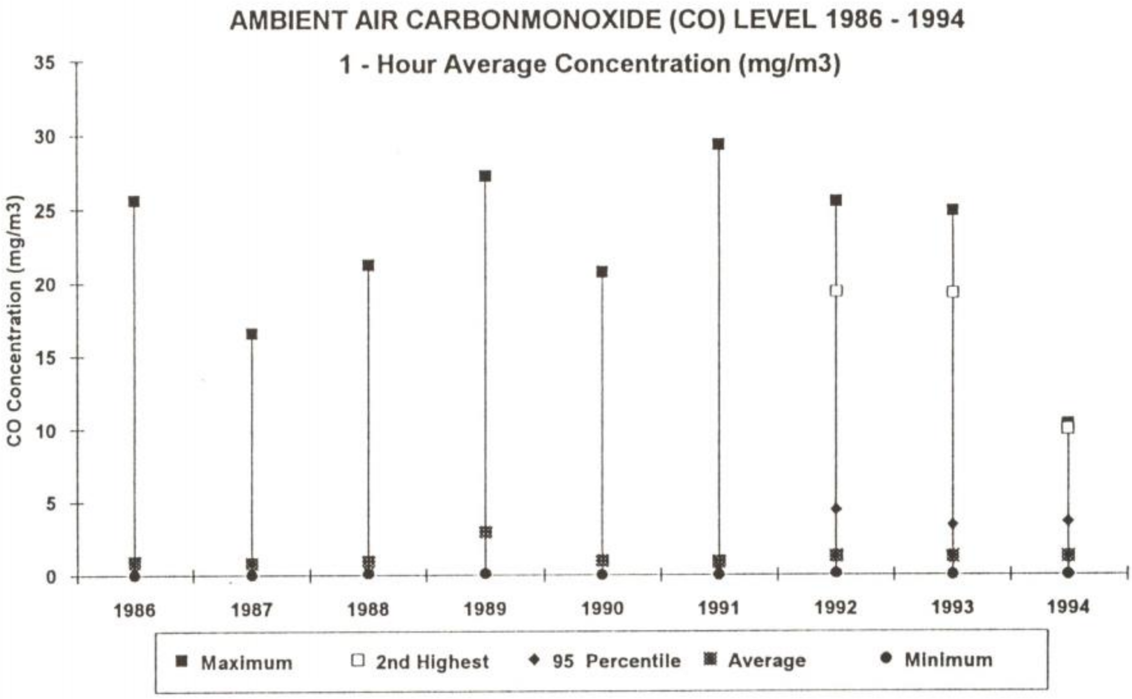


**Figure 4**

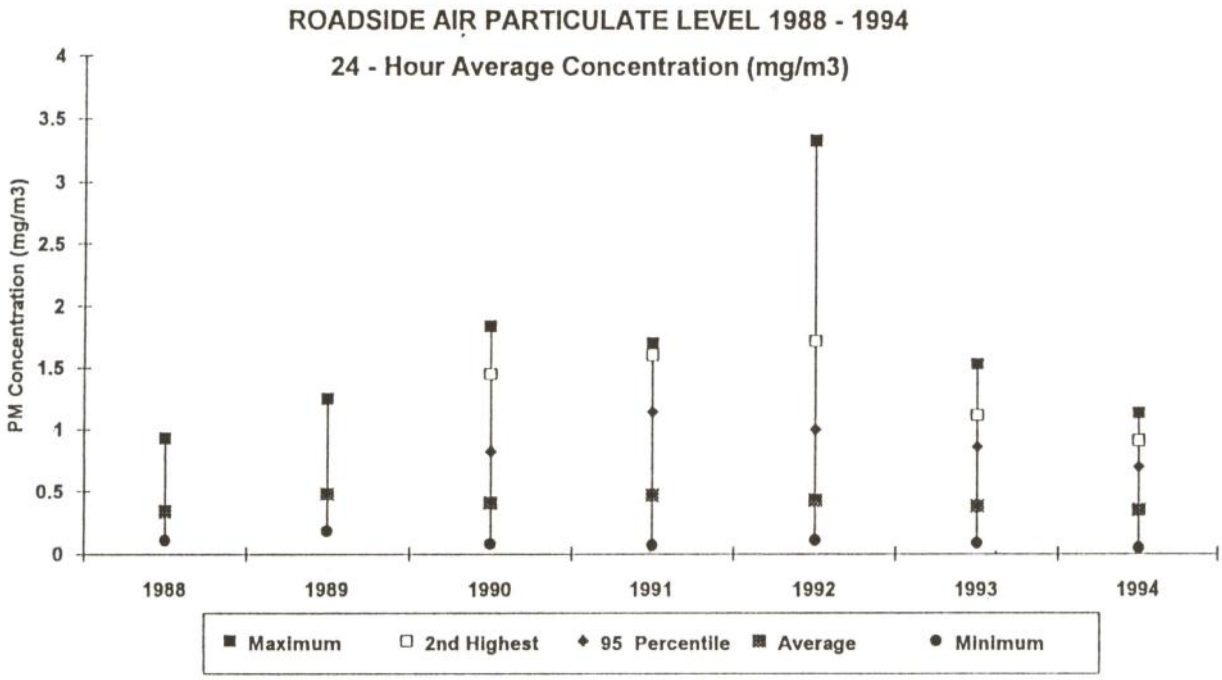


**Figure 5**

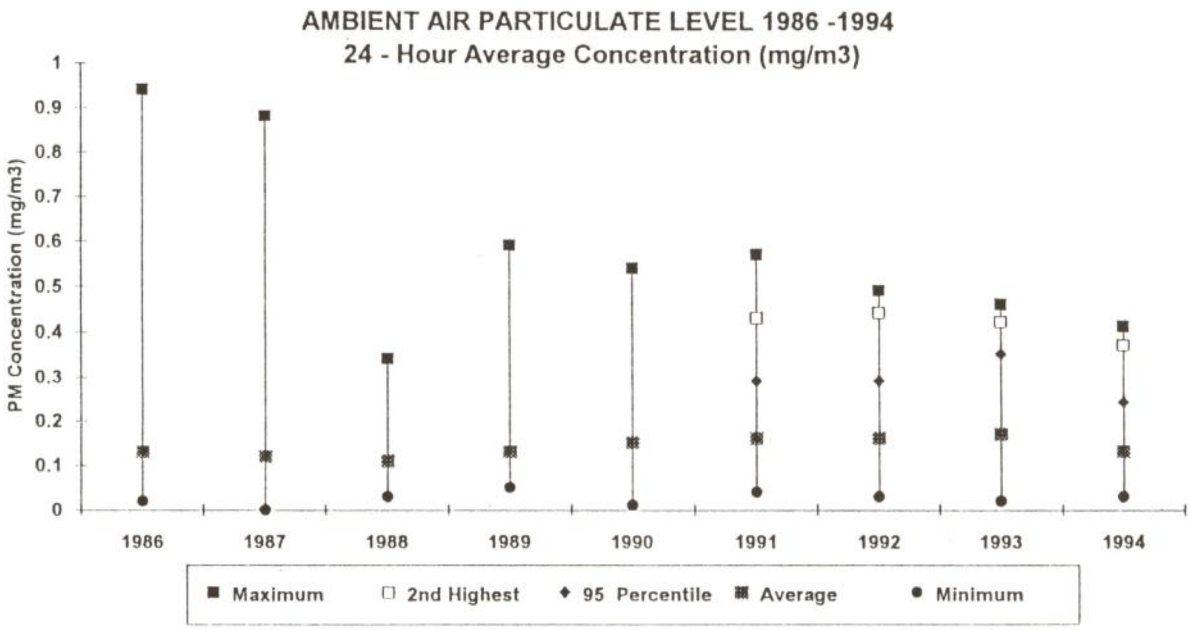


**Figure 6**