

Motor Vehicle Pollution Control

THE SUCCESSES AND ISSUES STILL CAUSING CONCERN AS THE NEXT MILLENNIUM BEGINS

By Michael P. Walsh

Consultant, 3105 North Dinwiddie Street, Arlington, Virginia 22207, U.S.A.

Over the past thirty years, countries around the world have gradually imposed increasingly stringent emissions regulations on the motor vehicle industry with the result that new cars today emit only a small fraction per mile driven of what they did when the process began. While increasing numbers of vehicles have offset some of these gains, air pollution levels are decidedly down in most industrialised countries.

The experience in Southern California's Los Angeles Basin, which has had the most aggressive motor vehicle pollution control programme in the world is just one example (1). From 1955 to 1993, peak ozone concentrations were cut in half, and the number of days on which Federal ozone standards were exceeded fell by 50 per cent from the 1976–78 time frame to the 1991–1993 interval. Further, the average annual number of days which exceeded the Federal carbon monoxide standard fell from 30 to 4.3 during this same period, and lead levels are now 98 per cent lower than in the early 1970s. Most remarkably, this achievement occurred while the regional economy out-paced the national economy in total job growth, manufacturing job growth, wage levels and average household income. During 1999, for the first time in memory, Los Angeles lost the distinction of being the most polluted city in the United States.

These clean technologies, originally developed for the U.S., Europe or Japan, are increasingly finding their way onto the roads of developing countries, with the result that air quality improvements are also occurring in many of them. About 80 per cent of all gasoline sold at the end of the millennium was unleaded and almost 90 per cent of all newly manufactured cars contain a noble metal based catalytic converter.

As we enter the new century, global vehicle emissions are substantially lower than they were, and much lower than they would have been if

aggressive vehicle pollution measures had not been taken. Based on my calculations, motor vehicle emissions of non-methane hydrocarbons are 67 per cent lower than they would have been, carbon monoxide emissions are 56 per cent lower and nitrogen oxides 18 per cent lower. It can even be said that in some cities the gases emitted by certain new cars are actually cleaner than the gases fed in!

However, it would be premature to declare victory and stop the fight. Most major industrialised countries continue to experience serious air pollution problems and even more serious problems exist in the major cities in developing countries. Further, vehicle growth continues, maintaining the pressure to bring all vehicle emissions down to lower and yet lower levels.

In this regard it is important to note that some vehicle categories, such as heavy duty diesel trucks and buses, have not yet been controlled to the same degree as cars. Further, new problems such as concern with ultrafine particles and global warming are emerging which will clearly require significant additional advances in vehicle technology in coming years.

This report will review the concerns associated with vehicle emissions, the trends in regulations to address these concerns, the progress made and significant remaining challenges.

Vehicle Growth Trends

As motor vehicle production is increasing at a more rapid rate than vehicle scrappage, worldwide vehicle registrations are sharply upward and are actually accelerating. At the end of the millennium the world's roads are supporting about 800 million vehicles, almost 500 million of which are cars, the remainder being commercial trucks and buses, motorcycles and scooters. The U.S., Japan and Europe account for the lion's share of the ownership and use of motor vehicles, but future growth is expected

| Table I U.N. Global Predictions of Population Growth, per cent | | | |
|---|----------|-------|-------|
| Region | 1950 | 1998 | 2050 |
| | billions | | |
| World | 2,521 | 5,901 | 8,909 |
| More developed regions | 813 | 1,182 | 1,155 |
| Less developed regions | 1,709 | 4,719 | 7,754 |
| Africa | 221 | 749 | 1,766 |
| Asia | 1,402 | 3,585 | 5,268 |
| Europe | 547 | 729 | 628 |
| Latin America and the Caribbean | 167 | 504 | 809 |
| North America | 172 | 305 | 392 |
| Oceania | 13 | 30 | 46 |

to be most rapid in Asia and Latin America where the majority of the world's 6 billion people reside. Looking to the future, population growth, increased urbanisation of the Asian and Latin American populations, and economic improvements are expected to continue the trend toward more and more vehicles, especially in the rapidly industrialising regions of Asia. According to the United Nations, the global population is projected to increase by an additional 50 per cent to 9 billion by 2050. Table I shows that this growth will not be evenly distributed but will be concentrated outside of the OECD, in Asia, Africa and Latin America.

Simultaneously, all regions of the world will continue to urbanise, with the greatest increases expected in Asia, see Table II. This is significant, since per capita vehicle populations are greater in urban than in rural areas.

According to the OECD, annual growth rates

in GDP (gross domestic product) over the next two decades will be highest in China, East Asia, Central and Eastern Europe, and the former Soviet Union, and this will further stimulate an increase in vehicle populations, see Table III.

Environmental Problems Associated with Motor Vehicle Emissions

Cars, trucks, motorcycles, scooters and buses emit significant quantities of carbon monoxide, hydrocarbons, nitrogen oxides and fine particles. Where leaded gasoline is used, vehicles are also a significant source of lead in urban air. This section will review some consequences of these pollutants.

(a) Photochemical Oxidants (Ozone)

Ground-level ozone is the prime ingredient of smog, the pollution which blankets many areas during summer (2). Short-term exposures (1 to 3

| Table II Annual Population Growth Rates | | |
|--|--|---------------------------------|
| Region | Urban Populations in 1999, per cent | Annual growth rate, per cent |
| East and North-east Asia | 40 | 2.7 |
| South-east Asia | 38 | 3.4 |
| South and South-west Asia | 31 | 3.1 |
| North and Central Asia | 68 | 0.4 |
| Pacific | 70 | 1.3 |

| Region | Years | | | | |
|----------------------------------|-----------|-----------|-----------|-----------|-----------|
| | 1995–2000 | 2000–2005 | 2005–2010 | 2010–2015 | 2015–2020 |
| Canada, Mexico and United States | 2.9 | 2.5 | 2 | 1.6 | 1.6 |
| Western Europe | 2.4 | 2.6 | 1.5 | 1.2 | 1.2 |
| Central and Eastern Europe | 3.6 | 4.5 | 4.1 | 3.6 | 3.6 |
| Japan and Korea | 0.75 | 2.25 | 1.5 | 1 | 1 |
| Australia and New Zealand | 3 | 3.1 | 2.2 | 1.75 | 1.75 |
| Former Soviet Union | -2.5 | 3.5 | 4.5 | 4 | 4 |
| China | 7.6 | 5.6 | 5 | 4.8 | 4.8 |
| East Asia | 2.4 | 4.8 | 4.8 | 4.5 | 4.2 |
| Latin America | 1.75 | 3.1 | 2.9 | 2.8 | 2.8 |
| Rest of the World | 2.75 | 3.2 | 3 | 3 | 3 |

hours) to high ambient ozone concentrations have been linked to increased hospital admissions and emergency room visits for respiratory problems. Repeated exposures to ozone can exacerbate symptoms and the frequency of episodes for people with respiratory diseases, such as asthma. Other health effects attributed to short term exposures include significant decreases in lung function and increased respiratory symptoms, such as chest pain and cough.

These effects are generally associated with moderate or heavy exercise or exertion. Those most at risk include children who are active outdoors during warm weather, outdoor workers, and people with pre-existing respiratory diseases. In addition, long-term exposure to ozone may cause irreversible changes in the lungs which can lead to chronic ageing of the lungs or chronic respiratory disease.

Ambient ozone also affects crop yield, forest growth and the durability of materials.

Ozone is not emitted directly into the atmosphere, but is formed by a reaction between VOC (volatile organic compounds) and NO_x (nitrogen oxides) in the presence of heat and sunlight. VOCs are emitted from a variety of sources: motor vehicles, chemical plants, refineries, factories, consumer and commercial products, and other industrial sources. VOCs are also emitted by natur-

al sources, such as vegetation. NO_x is emitted from motor vehicles, power plants and other sources of combustion.

(b) Particulate Matter

Particulate matter (PM) is the term for the mixture of solid particles and liquid droplets found in the air. PM includes dust, dirt, soot, smoke and liquid droplets which are directly emitted into the air from natural and man-made sources, such as wind-blown dust, motor vehicles, construction sites, factories and fires. Particles are also formed in the atmosphere by condensation or by the transformation of emitted gases, such as sulfur dioxide, NO_x and VOCs.

Scientific studies show that there is a link between PM (alone or in combination with other pollutants in the air) and a series of adverse health effects including breathing and respiratory symptoms, aggravation of existing respiratory and cardiovascular disease, alterations in the body's defence systems against foreign materials, damage to lung tissue, carcinogenesis and premature mortality. PM also causes damage to materials and soiling and it is a major cause of substantial impairment to visibility in many parts of the world.

Smaller particles are generally considered more hazardous than larger particles because they can penetrate beyond the natural defence mechanisms

of the body into the deepest recesses of the lungs where the greatest damage can occur. Particles emitted by motor vehicles and the particles formed by transformation of these gaseous emissions tend to be in the fine particle range (generally less than 2.5 μm in diameter). Scientific studies have linked fine particles (alone or in combination with other air pollutants), with a series of significant health problems, including premature death, respiratory-related hospital admissions and emergency room visits, aggravated asthma, acute respiratory symptoms including aggravated coughing and difficult or painful breathing, chronic bronchitis and decreased lung function which may be experienced as shortness of breath.

Other aspects of particles can also be important. The California Air Resources Board (CARB) has analysed over 30 human studies concerned with lung cancer risk and workplace exposure to diesel exhaust and found that workers exposed to diesel exhaust were consistently more likely than others to develop lung cancer. The consistent results are unlikely to be due to chance, confounding, or bias, according to CARB. As a result, CARB has concluded that a reasonable and likely explanation is a causal association between diesel exhaust exposure and lung cancer.

(c) Carbon Monoxide

Carbon monoxide (CO) is a tasteless, odourless and colourless gas produced through the incomplete combustion of carbon-based fuels. CO enters the bloodstream through the lungs and reduces the delivery of oxygen to the body's organs and tissues. The health threat from CO is most serious for those who suffer from cardiovascular disease, particularly those with angina or peripheral vascular disease, for unborn children and for very young children at the critical stage of their development.

(d) Nitrogen Oxides

Nitrogen dioxide (NO₂) can irritate the lungs and lower resistance to respiratory infection (such as influenza). NO_x emissions are an important precursor to acid rain and may affect both terrestrial and aquatic ecosystems. Atmospheric

deposition of nitrogen leads to excess nutrient enrichment problems (eutrophication), which can produce multiple adverse effects on water quality and the aquatic environment, including increased nuisance and toxic algal blooms, excessive phytoplankton growth, low or no dissolved oxygen in bottom waters, and reduced sunlight causing losses in submerged aquatic vegetation critical for healthy estuarine ecosystems. Nitrogen dioxide and airborne nitrate also contribute to pollutant haze, which impairs visibility and can reduce residential property values and revenues from tourism.

(e) Lead

Over the past century, a range of clinical, epidemiological and toxicological studies have continued to define the nature of lead toxicity, to identify young children as a critically susceptible population, and to investigate the mechanisms of action of lead toxicity. As noted by the "Environmental Health Criteria Document: Lead, Inorganic, No. 165", published in 1995 by the International Program on Chemical Safety (IPCS), lead affects many organs and organ systems in the human body, with subcellular changes and neurodevelopmental effects appearing to be the most sensitive. As noted by the IPCS, existing epidemiological studies do not provide definitive evidence of a threshold. Because of the serious health concerns, a global consensus has emerged to phase out the use of lead in gasoline and over 80 per cent of all gasoline now sold worldwide is unleaded (3).

(f) Climate Change

Greenhouse warming occurs when certain gases in the atmosphere allow sunlight to penetrate to the earth but partially trap the planet's radiated infrared heat. Some such warming is natural and necessary. If there were no water vapour, carbon dioxide (CO₂), methane, and other infrared absorbing (greenhouse) gases in the atmosphere to trap the earth's radiant heat, our planet would be about 60°F (33°C) colder, and life as we know it would not be possible. Naturally occurring greenhouse gases include water vapour, CO₂, methane (CH₄), nitrous oxide (N₂O) and ozone (O₃).

There are also several gases which, although

they do not have a direct global warming effect, do influence the formation and destruction of ozone, and ozone has a terrestrial-radiation absorbing effect. These gases include CO, NO_x and non-methane volatile organic compounds (NMVOCs).

Although CO₂, CH₄ and N₂O occur naturally in the atmosphere, the atmospheric concentration of each of them has risen, largely as a result of human activities. Since 1800, atmospheric concentrations of these greenhouse gases have increased by 30, 145 and 15 per cent, respectively (6). This build-up has altered the composition of the earth's atmosphere, and may affect the global climate system. According to a growing scientific consensus, if current trends in emissions continue, the atmospheric build-up of greenhouse gases released by burning fossil fuel, as well as industrial, agricultural and forestry activities, are likely to turn our benign atmospheric "greenhouse" into a progressively warmer "heat trap".

In late November 1995, the Intergovernmental Panel on Climate Change (IPCC) Working Group 1 concluded that "the balance of evidence suggests that there is a discernible human influence on global climate". In December, 1997, acting on this consensus, countries around the world approved the Kyoto Protocol to the 1992 Climate Change Treaty. Under this agreement, thirty-eight industrialised nations are required to reduce their "greenhouse" gas emissions from 1990 levels between the years 2008 and 2012. The European Union (EU) would reduce them by 8 per cent, the United States by 7 per cent and Japan by 6 per cent. As a group, the industrialised nations would cut back on the emissions of such gases by just over 5 per cent. The accord takes effect once it is ratified by 55 nations, representing 55 per cent of 1990 CO₂ emissions. It is binding on individual countries only after their governments' complete ratification. Implementing this agreement will require significant improvements in fuel economy to reduce CO₂ emissions from vehicles.

Rapid Progress is Occurring

To deal with these concerns, most regions of the world have been significantly tightening their motor vehicle regulations. Major developments

during the past twelve to twenty-four months have included the following:

- The EU has adopted Directives regarding light duty vehicle emissions and fuel quality which tighten standards significantly (in years 2000 and 2005), broaden the scope of coverage (for example, at cold temperature), added several important features previously missing (Onboard Diagnostics, in-use durability) and imposed low sulfur requirements for diesel fuel and gasoline.
- The U.S. EPA (Environmental Protection Agency) and the automobile industry, working in close cooperation with state air pollution officials, reached agreement to introduce voluntarily California's Low Emissions Vehicle Standards across the entire country.
- CARB then took emissions standards to the next level, not only tightening CO, HC, NO_x and PM requirements but also establishing the principles of fuel neutrality (that diesel vehicles meet the same standards as gasoline-fuelled vehicles) and usage neutrality (light trucks and utility sports' vehicles, used primarily as passenger cars, must meet the same standards as cars).
- China formally adopted the Euro 1 auto emissions standards and decided to phase out the use of unleaded gasoline across the entire country by 2000.
- Japan tightened their standards for gasoline-fuelled automobiles for the first time in twenty years and introduced the next phase of diesel-fuelled vehicle requirements.
- The Supreme Court of India banned the sale of leaded gasoline in Delhi as of September 1999 and mandated that all new cars meet Euro 1 auto standards (similar requirements will likely be phased in across the entire country by 2000).
- The U.S. EPA in conjunction with the CARB imposed the largest enforcement action in history on the heavy engine industry.
- The EU and the auto industry reached agreement on a voluntary commitment to reduce CO₂ emissions per kilometre driven by 25 per cent by about 2008.
- Taiwan adopted Step 4 of its motorcycle control programme, effectively banning two-stroke motorcycles by 2003.

- The CARB formally decided that diesel PM is a toxic air contaminant, triggering a process which will probably lead to an effort to further reduce PM emissions from urban vehicles.
- The Ministry of International Trade and Industry (MITI) in Japan and Japanese industry have reached agreement regarding lower CO₂ emissions from vehicles.

Thus, while much has been accomplished, several additional steps are underway:

- The U.S. EPA has recently proposed a further tightening of light duty vehicle standards (so-called Tier 2) as well as tighter sulfur requirements in gasoline.
- The EU is well along the road in deciding the next phase (or phases) of heavy duty standards.
- Increased attention is being focused on ultrafine PM from vehicles: diesel and also gasoline direct injection (DI) technology, increasing the likelihood that this will be a subject of control efforts in the future.
- On a global basis, pressure continues to build to lower the emissions of greenhouse gases (especially CO₂, CH₄ and N₂O by the transportation sector).
- The U.S. EPA has announced its intention to further tighten heavy duty engine emissions, with special focus on tighter PM and NO_x standards and the need for low sulfur diesel fuel.

The Remaining Challenges

While substantial progress has occurred in reducing vehicle emissions and further improvements in air quality are expected in most major industrialised countries in coming years, significant problems remain which require additional action beyond that noted above. Two of these problems will be discussed below.

(a) Particulate Emissions

While all regulation of diesel particulate from vehicles is based on the mass of particulate, several studies in recent years in the United Kingdom, Switzerland and the U.S.A. have increased interest in, and concern about, the number of very small ultrafine particles (4). Observations, that modern engines with reduced particle mass concentrations may actually emit larger numbers of particles than

Table IV
Comparison of Carcinogenic Potential of Diesel vs. Otto (4-stroke) – Passenger Car Exhaust

| Technology | Ratio Diesel vs. Otto |
|---------------------------------|-----------------------|
| Euro I with Catalyst | 4.5 |
| Euro II | 11.3 |
| Euro III | 17.5 |
| Euro IV | 14.7 |
| Euro IV with Particulate filter | 1.9 |

older designs, raise concerns that the form of future regulations should put more focus on the number of particles, in addition to, or as an alternative to, the mass. Additional studies indicate that large numbers of ultrafine particles may also be emitted by vehicles fuelled by gasoline and by CNG (compressed natural gas), at least at high speeds and loads, and especially from the more fuel efficient direct injection technology (5).

Studies are underway to characterise the size distribution of particles in ambient air and to understand the health consequences of these particles. Depending on the results of these studies, future vehicle regulation may focus more on these compounds. This could be muted, however, to the extent that mass based standards result in the use of particulate filters or traps as studies consistently show that these devices successfully reduce both the mass and the number of particles.

Beyond the particulate size concerns, studies indicate that diesel PM may be carcinogenic. The increased sales of light duty diesel vehicles, occurring in much of Europe, may therefore exacerbate the overall cancer risk. The Umweltbundesamt (UBA) in Germany has carried out a study which concludes that currently produced new diesel cars have a more than 10 times higher cancer risk than new gasoline-fuelled cars and the relative risk will be even greater when Euro III standards go into effect next year. However, according to the UBA, diesel cars complying with the Euro 4 (2005) vehicle emissions standards, if equipped with a particulate filter system, would have almost the equivalent cancer risk as a gasoline-fuelled car meeting the same standards. As summarised in

| Table V Comparison of Carcinogenic Potential of Diesel vs. CNG – Bus Engine Exhaust | |
|--|-----------------------|
| Technology | Ratio Diesel vs. Otto |
| Euro I | 117 |
| Euro II | 38 |
| Euro III | 24 |
| Euro IV | 13 |
| Euro IV with Particulate filter | 3.8 |

Table IV, they conclude that the relative cancer risk would be only approximately twice as high as from the gasoline-fuelled car.

Similarly, new heavy duty diesel vehicles equipped with PM filters and meeting Euro IV standards would have a four times higher carcinogenic potential compared to a CNG-fuelled vehicle as summarised in Table V, compared to almost 40 times higher today.

It appears that at least some diesel cars could comply with the Euro IV emissions standards without the use of particle filters. One manufacturer, Peugeot, has indicated that they will voluntarily introduce PM filters on some models next year. If other manufacturers follow suit, the concerns with ultrafine PM and increased cancer risks may be mooted. However, if they do not, it is likely that additional diesel regulation will follow.

(b) Global Warming

The greenhouse gases most closely identified with the transportation sector include CO₂, N₂O and CH₄. N₂O and CH₄ have the global warming potentials relative to CO₂ shown in Table VI.

| Table VI Global Warming Potentials Relative to CO ₂ | | |
|---|---------|---------------|
| IPCC GWP | Methane | Nitrous Oxide |
| 20 Year Horizon | 56 | 280* |
| 100 Year Horizon | 21 | 310 |
| 500 Year Horizon | 6.5 | 170 |

* For example, this means that 1 g of nitrous oxide has 280 times as much impact on global warming as 1 g of CO₂ over 20 years

However, it is important to note that other vehicle-related pollutants contribute to global warming although their quantification has been more difficult. These include CO, non-methane hydrocarbons (NMHC) and NO₂. According to the original (1990) IPCC report (7), global warming potentials have been attributed to these gases, see Table VII. Because of difficulty reaching agreement on the appropriate quantification, specific global warming potentials (GWPs) for these gases were not contained in the most recent IPCC report.

In most countries, over 90 per cent of the GWP of the direct acting greenhouse gases from the transportation sector comes from CO₂. The transportation sector is responsible for approximately 17 per cent of global CO₂ emissions and these emissions are increasing virtually everywhere.

However, some progress has begun, for instance, the European vehicle industry has recently adopted voluntary reductions in vehicle CO₂ emissions. The board of directors of the European Automobile Manufacturer's Association (ACEA) adopted:

- A target reduction in emissions of 140 g km⁻¹ of CO₂ for new cars by 2008.
- A 25 per cent reduction from the levels of 1995.

The ACEA also vowed to:

- Debut new cars emitting 120 g km⁻¹ of CO₂ or less by the year 2000.
- Review, by 2003, the feasibility of further reduction by 2012 towards 120 g km⁻¹ of CO₂ for all new cars.
- Set an estimated target range of 165 to 170 g km⁻¹ of CO₂ for 2003; and
- Establish a joint European Union/industry monitoring system for sharing achievements in CO₂ reduction.

The Big Three automakers (Ford, General Motors and Chrysler) and the U.S. government have been sharing high-tech information and manufacturing know-how since 1993 in an effort to serve mutually beneficial purposes. The programme is called the Partnership for a New Generation of Vehicles (PNGV) and matches engineers from the auto industry with government researchers from national laboratories, renowned

| Table VII Projected Global Warming Potentials from Gases | | | |
|---|----|------|-----------------|
| IPCC GWP | CO | NMHC | NO ₂ |
| 20 Year Horizon | 7 | 31 | 30 |
| 100 Year Horizon | 3 | 11 | 7 |
| 500 Year Horizon | 2 | 6 | 2 |

in the past for their work on military technologies. The goal is to create technology that will lead to a working model of a super-car by the year 2004 – a car capable of getting 80 miles to the gallon while meeting Tier 2 emissions levels or better.

In Japan, MITI and the Ministry of Transport (MOT) jointly drafted energy saving standards for automobiles and electric appliances on 13 October 1998, in compliance with the energy saving law. The draft standards were then adopted earlier this year. This will require a 21 per cent improvement in CO₂ emissions for all gasoline vehicles and a 13 per cent improvement for all diesel vehicles.

Conclusions

Continuing air pollution problems from vehicle-related pollution have been stimulating innovative pollution control approaches around the world. As these approaches are implemented, steady progress in reducing urban air pollution problems is being made. However, the vehicle population and kilometres travelled by vehicles continues to increase, especially in the rapidly industrialising developing countries. To keep pace with this growth, while lowering vehicle pollution even more, the U.S.A., Europe and Japan are continuing to push for even tighter controls in coming years. Controls initially introduced in these countries are gradually being adopted by other countries as well.

Beyond conventional pollutants, global warming concerns are increasing and the contribution from vehicles to this is rising all across the planet. To counter this problem, the major countries of the world have agreed to reduce greenhouse gas emissions (the so-called Kyoto agreement). To accomplish their commitments, countries will probably put increasing pressure on vehicle

manufacturers to improve vehicle efficiency or switch to renewable fuels.

One response to reducing greenhouse gases has been to increase the use of highly efficient diesels in the passenger car and light truck sectors. However, these vehicles emit higher amounts of NO_x and particulate than the gasoline-fuelled alternatives and have been linked to increased cancer risks. Further, some evidence indicates that currently applied technologies which reduce the mass of PM emitted may result in an increase in the number of very small particles. Since smaller particles have the potential to be ingested more deeply into the lung than larger particles, they may actually be more hazardous.

To respond to these challenges, a number of technological advances are needed by the industry; these include:

- Advanced low NO_x technology which can operate on lean burn engines with high efficiency without increasing N₂O emissions.
- Technologies which can not only reduce the mass of PM but also lower the number of ultrafine particles from future diesel and (DI) gasoline engines.
- Adaptation of low emissions technologies to off-road vehicles and engines.
- More durable emissions control systems which will last for the actual life of vehicles, as vehicle life continues to increase in many parts of the world; and
- Engine, fuel and control technologies which substantially lower greenhouse gases including, but not limited to, CO₂.

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The Author

Michael P. Walsh is an independent international consultant on motor vehicle pollution control and fuelling issues. He currently co-chairs the U.S. EPA's Mobile Source Advisory Subcommittee and is actively involved in government and industrial advisory projects in Hong Kong, Moscow and China.

Metallurgical Technology in the Scientific Revolution

METALS AND THE ROYAL SOCIETY

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It has long been recognised that good communication is essential for science to flourish. One of the ways in which The Royal Society, founded in 1660 and the oldest of the world's continuously-existing scientific academies, sought to improve the knowledge of natural things for the general good of mankind was by holding regular meetings of its members. In earlier times scientists communicated their thoughts and experimental data to "intelligencers" who collected and transmitted the information by letter to a network of scientific correspondents. As these scientific letters grew in importance, some scientists would have hundreds of copies of their letters printed, and widely distributed. Such developments stimulated the founding of the world's first scientific journal, the *Philosophical Transactions*, which later became an official publication for the Royal Society.

During the first two centuries of its existence, information about the metallurgical interests within the Royal Society was disseminated in the reports of numerous chemists, engineers, mathematicians and physicists. Now, two distinguished metallurgists have drawn from these contributions – written by over five hundred Fellows – and produced a volume which describes how metallurgy changed, first from an art to a science, then became recognised as a separate discipline, and was later extended to become materials science and engineering.

Readers of this Journal may recall that papers first recording the occurrence of platinum in the Chocó district of New Granada were confiscated from the

young Spanish naval officer, Antonio de Ulloa, by the British Admiralty but later returned to him following the intervention of Martin Folkes, the then President of the Royal Society. Thus, it is no surprise that one chapter in "Metals and the Royal Society" is entitled 'Precious Metals – the Platinum Group'. In fact, platinum metallurgy is one activity where the contribution from Fellows, including Percival Norton Johnson, George Matthey and Alan Richard Powell, can be traced for more than two centuries. Furthermore, most chapters concentrating on a particular subject area make reference to one or other uses of the platinum metals, or to the involvement of scientists who contributed to the advancement of platinum metallurgy.

Towards the end of the volume, two hundred and sixty-six pages are given over to biographies of some five hundred and sixty-nine Fellows and eighty-three Foreign Members whose work contributed to the metallurgical themes of this book. These are supported by a number of Appendices providing additional information mainly about their achievements.

Most readers are likely to be drawn to this worthwhile volume to check or extend their knowledge of a particular topic, or to investigate the work of an individual. However, the information within the book is so interesting that the reader will be stimulated to investigate the other chapters and fascinating biographies.

I. E. COTTINGTON

Ian E. Cottingham retired as editor of this Journal in 1994. He is interested in the history of platinum and its uses, and in new developments in platinum technology, especially for clean energy.