Too Easily Lead? Health Effects of Gasoline Additives

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Octane-enhancing constituents of gasoline pose a number of health hazards. This paper considers the relative risks of metallic (lead, manganese), aromatic (e.g., benzene), and oxygenated additives in both industrialized and developing countries. Technological advances, particularly in industrialized countries, have allowed the progressive removal of lead from gasoline and the increased control of exhaust emissions. The developing world, by contrast, has relatively lax environmental standards and faces serious public health problems from vehicle exhaust and the rapid increase in automobile use. Financial obstacles to the modernization of refineries and vehicle fleets compound this problem and the developing world continues to import large quantities of lead additives and other hazardous materials. Progress in decreasing environmental health problems depends both on the adoption of international public health standards as well as efforts to decrease dependence on the private automobile for urban transport. Key words: additives, aromatics, benzene, environmental exposure, gasoline, government policy, lead, manganese, octane boosters, oxygenates, toxicity, vehicle emissions. Environ Health Perspect 105:270–273 (1997).

After years of controversy (1), New Zealand completely removed lead from gasoline in 1996. Critics in New Zealand and elsewhere claimed that such a move was unnecessary, costly, and even a threat to public health.

In 1921, American chemist Thomas Midgely discovered the effective antiknock properties of tetraethyl lead and the use of this compound as an octane booster quickly spread (Midgely was later to develop CFCs as refrigerants) (2). By the 1970s, vast quantities of lead were added to gasoline as the world’s fleet of automobiles continued to grow (3). Combustion of leaded gasoline disperses lead compounds, particularly in cities and along major roads (4), and, together with socioeconomic and lifestyle factors, contributes to low-level lead burden in urban populations (3, 5).

In contrast to the frank toxicity in occupations and lead paint poisoning, low-level exposure of populations is an issue mainly because of evidence that it impairs children’s intellectual development (6–8). While low-level lead-associated intelligence quotient (IQ) deficits are unquestionably small (an average 0.25 IQ points per 1 µg/dl increase in blood lead level), they do apply to vast numbers of the world’s children (3, 7), and they could have substantial effects on the proportion of children with exceptional scores (8). For example, a 3-point drop in mean IQ would be expected to increase by 68% the number with very low (<65) scores and decrease by 42% those with very high (>135) scores (9). Thus, without detracting from the importance of other (e.g., socioeconomic, educational) factors that foster development and performance, IQ is crucial because it sets a limit on the extent to which such factors may contribute to an individual’s performance.

The effect of lead in gasoline on children’s intellectual development is controversial not because of its statistical significance but rather its magnitude. Apologists for lead additives have downplayed the importance of lead-induced cognitive deficits by arguing that these are small in comparison with population IQ gains over the last 20 years (10). This argument falters because the observed IQ increase is a pseudogain; there is no evidence to indicate any real increase in intelligence. Nonetheless, IQ does reflect reasonable ranking of individuals within a culture at a given time. Thus, IQ deficits in lead-exposed children relative to their less-exposed peers may be important, particularly given plausible neurotoxic mechanisms. By interfering with calcium channels (11) and protein kinases (12), low concentrations of lead may disrupt transmembrane signaling and, crucially, synaptogenesis (12).

In addition to its direct health effects, lead in gasoline requires the addition of chemical scavengers to inhibit lead accumulation in the engine. Combustion of these scavengers has been linked to halogenated dibenzo-p-dioxins and dibenzofurans in exhaust (13) and may confer a cancer risk to exposed individuals (14). A further disadvantage of lead in gasoline is that it fouls catalytic converters, which have the potential to remove up to 90% of toxic emissions in exhaust from engines running on unleaded gasoline. Thus a combination of factors, including a growing requirement that new cars be fitted with catalytic converters, has caused a progressive restriction of lead in gasoline in the industrialized world (Fig. 1), particularly in countries belonging to the Organisation for Economic Co-operation and Development (OECD) (15).

The association of lead in gasoline with poverty (suggested in Fig. 1) was examined by correlating lead with per capita gross national product (GNP) (16). As shown in Figure 2, poorer countries tend to have higher amounts of lead in gasoline, probably due to older vehicle fleets and refineries as well as more lax environmental standards. This correlation remains even within the group of industrialized (OECD) countries, none of which allows lead in gasoline above 0.45 g/liter. On the other hand, some low-income countries (e.g., Brazil) have virtually eliminated lead in gasoline due to availability of cheap alternatives (in this case, ethanol from sugar cane).

Alternatives to Lead
Whereas many newer vehicles run on low 91-octane unleaded gasoline, older and high-performance cars often require higher (up to 98 or 100) octane. With the restriction of lead, other means of boosting octane include, in order of increasing cost: another metallic additive, methylcyclopentadienyl manganese tricarbonyl (MMT); changes in the refining process to increase aromatics or olefins; and addition of oxygenates such as methyl 2-buty1 ether (MTBE), related ethers, ethanol, or methanol.

Increasing the proportion of aromatics in gasoline has been the most common, and the most controversial, means of lead-free octane enhancement. The main concern arises from the simplest aromatic compound, benzene, which is a minor component of most gasoline but is also produced by other aromatics during combustion. Benzene is a human carcinogen and is most clearly associated with acute myelocytic leukemia in exposed workers (17). Although exposure data are incomplete, benzene air pollution from gasoline may pose a cancer risk to taxi drivers, gasoline pump attendants, and refinery workers (18).

At least 80% of the benzene in urban air is thought to arise from the exhaust emissions of gasoline engines (19). Concentrations of benzene in the urban air of OECD countries range between 1 and 10 parts per billion (ppb) (20) depending on traffic volume and

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proximity. Somewhat surprisingly, indoor exposure to benzene often exceeds outdoor levels. In the United States, for example, overall mean benzene exposure of the general population (5 ppb) exceeds the mean outdoor atmospheric concentration (2 ppb). Indoor benzene exposure derives from a number of sources including tobacco smoke, but in naturally ventilated urban buildings up to 70% may be attributable to vehicle emissions (21). Such trapping of benzene also occurs in cars, as shown by studies in the United States and Sweden, where in-car levels of benzene were three to eight times higher than in ambient air (22). It has been postulated, but far from proven, that exposure to high in-car benzene levels may be responsible for clusters of childhood leukemia (23).

In the United Kingdom, the Department of the Environment Expert Panel on Air Quality Standards recommends a maximum of 5 ppb as a short-term annual average for benzene exposure with 1 ppb as a long-term goal. In order to curtail atmospheric benzene, OECD countries have generally restricted gasoline content to 5% benzene, although the United States has a limit of 1% and Japan and some Western European countries have or are considering a limit of 3% (19). Up to 1% of gasoline benzene remains uncombusted and, in the absence of catalytic converters, contributes about half of the benzene tailpipe emissions; another 40% is derived from other aromatics. In New Zealand, the move to unleaded 96-octane gasoline has caused an average increase of 8% in total aromatic content (from 36 to 44%) and in tailpipe emissions of benzene. On the other hand, removal of leaded gasoline will allow the introduction/retention of catalytic converters (currently removed from imported cars that require a minimum octane of 95), which effectively trap a variety of toxic emissions, including aromatics, other volatile organic compounds, carbon monoxide, and oxides of nitrogen. Somewhat ironically, in the presence of catalytic converters, higher aromatic gasoline may have advantages as it further decreases the production of nitrogen oxides and hence ozone and smog (24).

Other octane boosters. Relatively low concentrations of MMT are required to boost octane; the manganese content of up to 18 mg/liter is similar to the amount of lead allowed in unleaded gasoline. The effects of MMT on vehicle exhaust emissions appear favorable, particularly as it can reduce production of nitrogen oxides (25). The health effects of MMT are incompletely understood, but some comfort has been taken from the fact that the predominant combustion product, manganese tetroxide, is of low bioavailability. Canadian studies have shown increased manganese levels in exposed individuals, but airborne exposure accounted for less than 1% of absorption (26,27). Although these studies have concluded that the compound is probably safe, it is not known what problems may ensue if its widespread use occurs in settings of high traffic density. There is also the question of the potential neurotoxicity of manganese, which is yet to be linked to MMT in gasoline. The compound is approved for use in Argentina, Australia, Bulgaria, Canada, Russia, and conditionally in New Zealand. The U.S. Environmental Protection Agency has decided the use of MMT is compatible with catalytic converters and has granted a waiver for its use in unleaded gasoline in the United States. The European Union and Japan have thus far opted against MMT.

Oxygenated additives (up to 15% by volume) increase the oxygen content of gasoline, promoting more complete combustion and reducing carbon monoxide emissions, especially in winter. The costs of increasing octane by adding MTBE or ethanol are relatively high. Other disadvantages of oxyfuels include aldehyde combustion products, which are reported to worsen smog (28) and have been associated with various physical symptoms (29). Although MTBE is thought to be only weakly car-
cinogenic and may be less of a risk in this regard than other constituents of gasoline (30), it has been found to accumulate in body fat and has a number of potentially toxic breakdown products including methanol, formaldehyde, and 2-butanol (31). The use of oxyfuels is restricted mainly to Europe and North America and remains highly controversial (32,33).

**Discussion**

Octane-enhancing gasoline constituents pose a variety of health risks that have been minimized, particularly in the OECD, by the restriction of lead and the increasing requirements for emission controls. In the developing world, such environmental safeguards are often lacking, and high levels of lead additive are common (Fig. 1, 2). Interestingly, the persistence of leaded gasoline in the poorer countries means that imported used vehicles from Japan, Europe, and the United States typically have their catalytic converters detached and junked, thus compounding emission risks.

What is the role of industry in all of this? The world's major producer of tetraethyl lead has lobbied against the progressive exclusion of lead from gasoline, and has emotively equated the carcinogenic risk of benzene with that of asbestos and cigarettes. In full-page newspaper advertisements in the United Kingdom, New Zealand, and elsewhere, the same company downplays the risk of lead by labeling it "a naturally occurring toxin, as are alcohol, sugar, and salt." Although public health is the stated concern, one can only speculate on the commercial exigency in developed countries, as well as in the less restricted markets in Asia, Africa, and Latin America.

The public health and urban planning problems posed by excessive reliance on the automobile in OECD countries (34,35) are likely to be dwarfed by those emerging in the Third World, with its growing population (36,37), increasing urbanization (36), rapidly expanding use of cars and fossil fuels (38), and less stringent environmental safeguards (39,40). On the other hand, the increasing availability of unleaded gasoline in the developing world means that the benefits of emission control technology, driven largely by regulations in the United States, will gradually trickle down. Incentives to take advantage of this technology, and to get rid of older vehicles that create more pollution, may be helpful, particularly if combined with laws requiring that all new vehicles must be able to run on unleaded 91-octane gasoline. Various strategies have been used to encourage updating vehicle fleets, including differential taxation of leaded gasoline (e.g., Australia) and older vehicles (e.g., Singapore). Like the conversion to unleaded gasoline, such incentives would require the allocation of scarce resources, and progress is likely to be slow in developing countries with urgent competing priorities (41).

Technological problems aside, it has been argued that on a worldwide basis there are already too many cars to be compatible with public health or environmental sustainability, let alone as efficient transport in cities (35,42). The enormous popularity of driving raises ethical questions about how individual freedoms are to be balanced against public health. The removal of lead from gasoline and the development of cheap and efficient urban public transport are two examples of how such a balance can be addressed by responsible government.

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