

The Global Experience With Lead in Gasoline and the Lessons We Should Apply to the Use of MMT

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Background *As leaded gasoline is on the verge of being eliminated from all gasoline worldwide another neurotoxin has been put on the market as a lead substitute. Initial concerns regarding the potential adverse health impacts of this additive have emerged and some evidence indicates that its use could damage pollution controls on advance gasoline fueled vehicles.*

Methods *This paper attempts to draw upon the experience with lead in gasoline to see what lessons we should have learned and how these lessons should apply to the use of the new additive, methylcyclopentadienyl manganese tricarbonyl (MMT).*

Results *Based on the global experience with lead, the question is whether we have sufficient information to conclude that the precautionary principle should apply to the use of MMT.*

Conclusions *This would require the developer of the additive to demonstrate conclusively that it is safe before it is sold around the world.* Am. J. Ind. Med. 50:853–860, 2007.

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KEY WORDS: *manganese; MMT; gasoline; environmental exposure; health effects*

INTRODUCTION

In February 1923, leaded gasoline was first sold to the public in the United States [Loeb, 1999]. This began a more than 80-year experiment using the children of the world to determine the significant adverse impacts of lead [Rosner and Markowitz, 1985]. That experiment has demonstrated that millions of children suffered serious adverse health impacts from exposure to this toxic metal. In spite of this, leaded gasoline is still marketed and sold today in some developing countries. The same company that produced and sold the gasoline lead additive has come up with a substitute octane enhancer, methylcyclopentadienyl manganese tricarbonyl (MMT), and is aggressively marketing it in developing countries around the world. Based on the global experience with lead, the question is whether the MMT experiment should be carried out on our children or whether we have learned enough to conclude that the precautionary principle

should apply, requiring the developer of the additive to demonstrate conclusively that it is safe before it is sold around the world.

Methylcyclopentadienyl manganese tricarbonyl (MMT) is an octane enhancer that forms manganese particles when burned as a gasoline additive. These particles can be emitted to the atmosphere or deposited on engine and vehicle components, causing concern in either case. Manganese can be a potent neurotoxin when inhaled [ATSDR, 2000] and automakers are concerned that deposited manganese can damage pollution control systems and increase emissions, perhaps preventing new cars from meeting the most advanced emissions standards. A growing body of scientific evidence has begun to expose the mechanisms of impact in humans and vehicle systems. Makers of MMT, however, continue to argue that the evidence is flawed and insufficient.

The Ethyl Corporation, the principal producer of MMT, was founded in the 1920s to manufacture market and sell tetraethyl lead as an octane-enhancing additive for gasoline. It started out as the General Motors Chemical Company in 1923 and became the Ethyl Gasoline Corporation in 1924. In 1942, the name was further simplified to the Ethyl Corporation [Ethyl, 2004]. In 2004, “Ethyl Corporation transformed into NewMarket Corporation, the parent company of Afton Chemical Corporation and Ethyl Corporation,” in order to “maximize the potential of its operating divisions—petroleum

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additives and tetraethyl lead” [Afton, 2004]. Afton Chemical took over production and sales of MMT and Ethyl retained the tetraethyl lead product. (To avoid confusion, the New-Market Corporation, Afton Chemical Corporation, and Ethyl Corporation will be referred to collectively as Ethyl in this paper.)

As lead was phased down in North America beginning in the 1970s, Ethyl began to market MMT as a lead replacement. Since that time, the impact of MMT on human health, the environment, vehicles, and vehicle emissions has been the subject of a great deal of research. Even so, there continues to be substantial controversy regarding MMT: automakers are widely opposed to its use; many public health advocates and regulatory agencies are concerned about the potential health impacts; and Ethyl continues to vigorously defend its product as safe and effective.

This paper will review the experience with lead in gasoline and some of the important lessons that should be learned from that experience. It will then attempt to apply those lessons to the use of MMT.

THE USE OF LEAD IN GASOLINE AND THE LESSONS LEARNED

At the present time as illustrated in Figure 1, over 95% of all gasoline sold in the world is lead-free. However, sales of lead continue in a number of North African, Central European, and Asian countries.

Lesson #1: Reducing Lead in Gasoline, Reduces Lead in Our Children’s Bodies

As lead has been phased out of gasoline around the world, there has been a consistent steady decline in the lead content in the blood of the general population, including especially children.

For example, Figure 2 shows the experience in the United States during the mid 1970s to early 1980s when lead



FIGURE 1. Worldwide status of lead free gasoline 2006. Source: Partnership for Clean Fuels and Vehicles [2007].

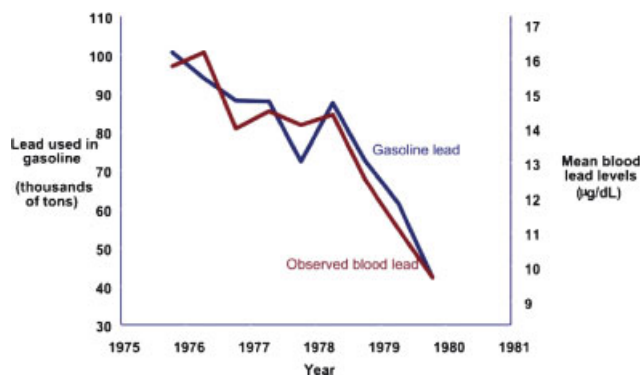


FIGURE 2. Lead used in gasoline compared to mean blood lead levels. Source: Annest et al. [1982]. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

was being phased out of gasoline. This data illustrates clearly that as lead was reduced from gasoline the mean blood lead levels in the general population also came down in a highly correlated fashion.

The US experience has subsequently been duplicated in other countries. For example, as shown in Figure 3 which summarizes the ambient lead levels at several locations in Delhi, India before and after the elimination of lead in gasoline, on average lead levels were reduced by over 50% in less than 1 year.

Similarly in Bangkok, the lead in ambient air came down in direct proportion to the lead in gasoline as shown in Figure 4. More importantly, as shown in Figure 5, as ambient lead levels were reduced, the lead content in the blood of Thai children was also reduced dramatically, on average by over 40%. Furthermore, the fraction of children with blood lead levels exceeding 10 µg/dl came down even more dramatically as shown in Figure 6. (At that time, 10 µg/dl was considered the safe level.) While there are potentially many sources of lead exposure—leaded paint, water from lead pipes, proximity to lead smelters, etc.—it is remarkable how reducing or eliminating lead in gasoline has been shown to reduce lead exposure across such diverse countries and cities.

Nanogram per cubic Meter

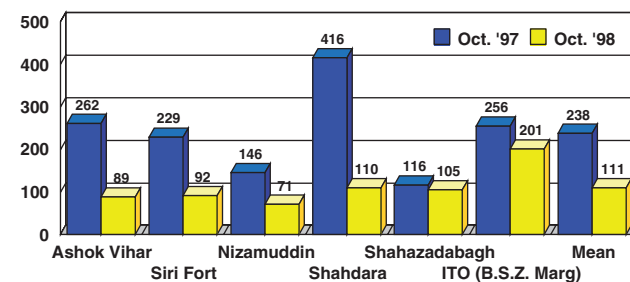


FIGURE 3. Ambient particulate lead in Delhi pre and post unleaded petrol. Avg. reduction 53%. Source: Central Pollution Control Board [2000] personal communication. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

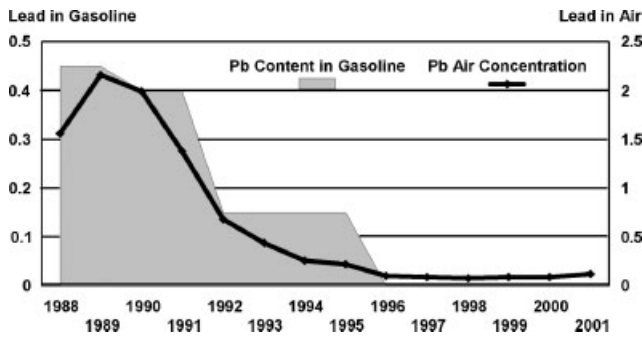


FIGURE 4. Ambient Pb concentrations in Bangkok and Pb in gasoline from 1988 to 1998. Source: Wangwongwatana [2004].

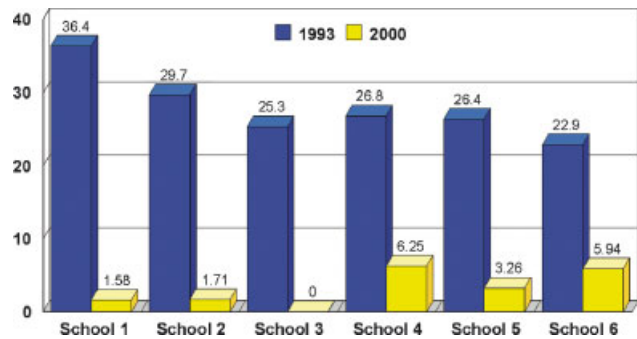


FIGURE 6. Percentage of school children with blood Pb levels above 10 mg/dl. Source: Wangwongwatana [2004]. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

Lesson #2: The More We Know, the Greater the Concern!

Over the course of this same period, a great deal was learned about the health risks of lead exposure especially to children. As a result, the blood lead level considered unsafe was gradually lowered from 25 to 10 µg/dL. Recent studies indicate that even this level is insufficient.

For example, in 2003, results of a new study were published in the New England Journal [Canfield et al., 2003]. In this study, 172 children were tested at 6, 12, 18, 24, 36, 48, 60 months. Most of the children, over 100 children were never found to have blood lead levels above 10 µg/dl. However, even after correcting for confounding variables, blood lead was significantly associated with IQ. An increase of from 1 to 10 µg/dl was found to cause more than a 7 number IQ loss, as illustrated in Figure 7.

Most health scientists today would agree that there is likely no safe threshold for lead, that is, even at very low levels, adverse and likely permanent damage to the health of children will occur.

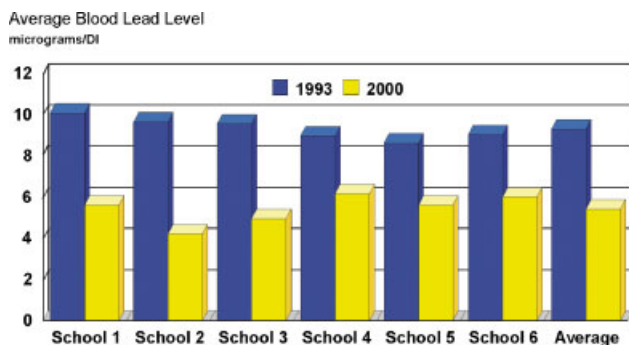


FIGURE 5. Comparison of average blood Pb levels in children at 6 schools in Bangkok between 1993 and 2000. Wangwongwatana [2004]. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

Lesson #3: Lead Free Fuel Facilitates Other Advanced Pollution Controls

During the 1970s as the evidence was accumulating that lead in gasoline was causing serious health damage to children, other evidence was accumulating that other emissions from gasoline fueled vehicles was also causing serious adverse health and other environmental damage. The pollutants of greatest concern were hydrocarbons (HC), carbon monoxide (CO) and nitrogen oxides (NOx). Certain hydrocarbons such as benzene and polynuclear aromatics were considered especially hazardous. The best technology that emerged at that time with the capability to substantially reduce most of these vehicle emissions was the catalytic converter.

However, it soon became clear that this technology could not be used with leaded gasoline. Just a few tanks of leaded gasoline caused permanent damage to the catalyst, leading to substantial increases in emissions of CO, HC, and NOx. Therefore a second motivation for phasing lead out of gasoline became the need to protect the most significant

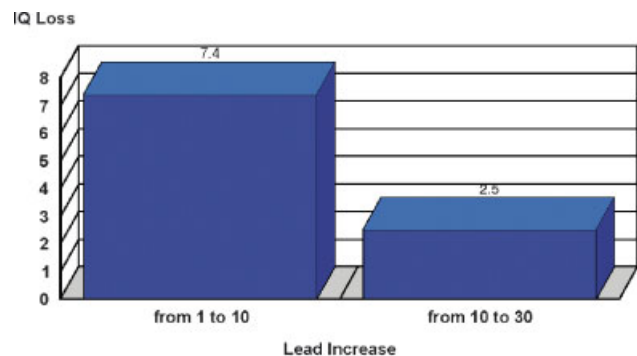


FIGURE 7. IQ loss as lead in blood increases. Source: Canfield et al. [2003]. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

pollution control device. This US experience has been repeated around the world—as leaded gasoline was phased out or banned, catalyst forcing emissions standards were introduced to reduce the other important vehicle emissions. So today, in addition to over 90% of the gasoline worldwide being unleaded, over 90% of all new gasoline fueled vehicles come equipped with three way catalysts. This includes all new cars in China, India, Viet Nam, Brazil, Chile, and many other rapidly industrializing developing countries.

Lesson #4: Companies Will Continue to Sell The Product Until Banned!

In spite of all that is known today about the health consequences of lead in gasoline and the need for lead free fuel to clean up the other noxious gases from vehicles, leaded gasoline is still produced and sold today. In its 2005 Annual 10-K Report, Ethyl noted that “We do expect that the demand for this product will continue for many years to come, but at a significantly lower level of volume and profits” [New-Market, 2005]. Sellers of the additive argue that it would be harmful to these remaining leaded countries to switch to unleaded fuel because they do not yet have a majority of cars with catalysts and therefore emissions of hazardous hydrocarbons such as benzene might go up. This would be especially true if increased use of benzene and aromatics were used in gasoline to substitute the octane that is needed if lead is eliminated. But of course they don’t have catalysts because they have leaded gasoline.

A good case in point is the country of Indonesia, the 4th most populous country in the world. The Indonesian Minister for Environment adopted catalyst forcing standards a few years ago but has had difficulty implementing the requirement because leaded gasoline was still being sold in many parts of the country. Indonesia’s government adopted the “Blue Sky” initiative in 1996 which targeted 2000 as the lead phase-out date. A regeneration of “Blue Sky” in July 1999 aimed at January 2003 for leaded gasoline removal. In 2003, Indonesia’s government expressed its intention to ban leaded gasoline in 2005. However, the lead industry resisted each step of the way. The lead industry continues to argue that lead free fuel is too expensive, causes energy penalties and “there is no medical evidence on the effects of lead on health to oppose the view that the orderly gradual lead phase-out in Indonesia which is already underway, should continue” [Emphasis added]. The author continued, “Aromatics, which include benzene, together with oxygenates such as alcohols, are by far the most popular octane enhancers employed worldwide. But these gasoline components increase the cancer inducing, smog-forming, lung irritant potential and the acid rain content of exhaust gas from “non-cat” vehicles” [Larbey, 2004]. In late 2006, Indonesia finally implemented the complete lead phase out but not without

another public effort to persuade the government to reverse course [Larbey, 2006].

Conclusions Regarding Lead in Gasoline

Over the past 40 years, as study techniques and methodologies became more and more sophisticated, the adverse health effects of lead at lower and lower levels have become increasingly clear. As lead has been removed from gasoline around the world, ambient lead levels have been reduced and lead concentrations in the blood of the population have come down dramatically, especially in children. Further, the introduction of lead free gasoline has opened up the possibility of very substantial improvements in the CO, HC, and NOx emissions from vehicles using catalyst technology with the result that this technology is now used in the vast majority of new cars all across the developed and developing world. Only in countries where leaded gasoline is still available or where lead has only recently been banned do new cars still not have catalysts.

Finally, in spite of this overwhelming body of evidence regarding the adverse impacts of lead, leaded gasoline is still used in a number of developing countries where the lead industry continues to overemphasize its benefits and downplay its hazards.

CONCERNS REGARDING THE USE OF MMT

The same concerns which have been raised with regard to lead have also been raised with MMT—direct adverse health effects and potential damage to advanced vehicle pollution control systems.

Health Concerns

A study published by the Health Effects Institute (HEI) explored the mechanisms for transporting manganese into and out of the brain. Yokel and Crossgrove [2004] reported that the transport rate of manganese out of the brain is slower than the transport rate for manganese entering the brain, indicating that a mechanism exists by which manganese may accumulate in the brain with chronic exposure.

Other studies have shown that fine particles containing manganese can be absorbed into the blood through the lungs and ferried directly into the central nervous system and brain [Dobson et al., 2004].

Manganese associated with fine particles also enters the brain directly via the nasal passages, which contain nerves that have been shown to transport manganese into the brain [Tjälve et al., 1996]. Ultra-fine particles (<100 nm) represents an even higher risk for humans. As recently demonstrated in rats, these particles can be transported through the olfactory neuronal pathway to the central nervous system and result in inflammatory changes [Elder

et al., 2006]. Particles do not need to dissolve to spread, and inhalation pathways can be more efficient than circulatory ones.

The right nostril of several rats was closed and manganese oxide was inhaled through the left nostril. The vast majority of manganese quickly accumulated in the left olfactory bulb. This excluded that accumulation was due to other routes, such as the circulatory system; otherwise, the manganese would have appeared in both olfactory bulbs. This finding contrasted with a similar study by Dorman et al. [2004], where poorly soluble manganese phosphate particles were used that were several orders of magnitude larger than the approximately 30-nm manganese oxide agglomerates used by Elder et al. [2006]. The particles in this study were about one-sixth the diameter of the olfactory neurons, along which the agglomerates moved into the brain [Weinhold, 2006].

Preliminary data indicate that Mn inhaled during pregnancy can have significant adverse effects on neurological development in the offspring. In recent work Professor Kleinman of UC Irvine examined “groups of pregnant rats exposed to Mn aerosol or saline aerosol (control) during the second and third weeks of gestation” [Kleinman, 2006]. The total dose of Mn from inhaled MnSO₄ (estimated using a computer model of particle deposition) was less than 1% of the Mn ingested from the diet and water by the dams. The pups were born naturally and nursed until they were weaned. After weaning the pups were challenged with injected methamphetamine or saline. The animals were euthanized and brain tissue was examined biochemically to look at dopamine, serotonin and their metabolites and histologically to examine the structure of neuron bundles. The pups from Mn-treated dams had significantly greater responses to the methamphetamine challenge compared to pups from control dams. The neuronal structure was significantly altered in the brains of pups from Mn-treated dams.

The impact of low-level, chronic exposures is unclear, especially for sensitive populations such as infants, pregnant women, the elderly, and people with liver disease or iron deficiencies [Mena et al., 1969; Zayed, 2001]. Potential adverse effects are expected to be subtle and difficult to detect [Zayed, 2001], which could result in widespread damage before MMT use is stopped.

The Health Effects Institute [Health Effects Institute, 2005] recently summarized certain concerns when it noted that “There is a large body of evidence that (1) under certain circumstances, manganese can accumulate in the brain [Hauser et al., 1996; Lucchini et al., 2000], (2) chronic exposure can cause irreversible neurotoxic damage over a lifetime of exposure, (3) manganese may cause neuro-behavioral effects at relatively low doses [Roels et al., 1992], and (4) these effects follow inhalation of manganese-containing particles (neurotoxic effect of dietary manganese are much more rare) [ATSDR, 2000].” In this context, HEI highlights the

recent study by Yokel and notes that his “findings have serious implications for how to interpret the effects of long term exposure to manganese.”

Vehicle Concerns

Beyond direct health effects, as with lead, vehicle manufacturers have raised concerns regarding the impact of the additive on vehicle pollution control technologies. A coalition of the Alliance of Automobile Manufacturers (AAM), the Association of International Automobile Manufacturers, and the Canadian Vehicle Manufacturers Association and others completed a comprehensive MMT test program [Alliance of Automobile Manufacturers AAM, 2002a,b]. And in 2004, Ford completed a post-mortem analysis of the Escorts used in the AAM study. In focused testing on Low Emission Vehicles (LEV), the AAM study found that MMT increased emissions of hydrocarbons (HC) over the entire 100,000 miles of testing, causing seven of the eight light-duty vehicles tested to exceed LEV certification standards. Nitrogen oxide (NO_x) emissions were initially lower for MMT-fueled vehicles, but increased over time, as did emissions of carbon monoxide (CO), to become much higher than clear-fueled vehicles at 100,000 miles. MMT increased emissions of all three pollutants at the end of the study by an average of 31–37% and reduced fuel economy over the life of the program by 2% or 0.6 mpg [Benson and Dana, 2002]. The emissions impact of MMT was especially dramatic in Ford Escorts designed to meet LEV standards. In order to examine the mechanisms of impact, Ford swapped parts between the MMT- and clear-fueled Escorts used in the AAM study and published their findings in a 2004 Society of Automotive Engineers (SAE) technical paper [McCabe et al., 2004]. Ford demonstrated that HC and CO emissions were mainly impacted by manganese deposits on the cylinder head and spark plugs and those higher NO_x emissions were linked to manganese deposits on the catalyst, which was approximately 20% blocked after 100,000 miles. Complete exchange of clear-vehicle components with MMT-vehicle components increased emissions in the Ford Escorts by 118% for HC, 130% for CO, and 143% for NO_x [McCabe et al., 2004].

Concerns with the impact of MMT on vehicle emissions have already begun to emerge in the developing world, as illustrated in Figure 8 from Volkswagen [Schindler, 2004].

THE STATUS OF MMT USE AROUND THE WORLD

MMT is currently used only sparsely in the developed world. The major refiners in Canada have voluntarily stopped using MMT, out of concern for the impact of MMT on advanced vehicles and pending the results of an upcoming



FIGURE 8. Experience with MMT. China: Blocked catalytic converter. Source: Schindler [2004].

review of the issue in Canada. As a result, as much as 95% of Canadian gasoline is now MMT-free [Inside Fuels, 2004]. MMT is not currently allowed in reformulated gasoline (RFG) in the U.S. and is not used at all by any of the major oil companies in the United States. RFG is gasoline blended with oxygenates to reduce ozone-forming and toxic pollutants, primarily from older vehicles. RFG is required by the Clean Air Act to be used in cities with the worst smog pollution. It is used in many of the major cities and most populous regions of the U.S., that is, throughout most of the East Coast, the Chicago region and some other major Midwestern cities, Dallas and Houston in the South, and California in the West. The State of California, which has driven the trend toward low emissions standards around the world, banned manganese additives in unleaded gasoline in 1976 [Lloyd, 2004]. New Zealand effectively banned use of MMT in 2002 by restricting manganese levels in gasoline to a maximum of 2.0 mg Mn/L [New Zealand, 2002]. MMT has not received approval for use in Germany, where the so-called Gasoline-Lead Law requires the producers to demonstrate there is no additional risk caused by a metal additive to gasoline [Friedrich, 2004]. Elsewhere in Europe, MMT is used in only a couple of the Eastern countries and perhaps by one small refiner in Belgium. MMT is not used in Japan, which was one of the first countries to completely ban lead [Menkes and Fawcett, 1997; United Nations Environment Program (UNEP, 1999)]. Ethyl has declined a request to identify the countries where the additive is being sold and the amounts used in those countries but according to its 2003 Annual Report at that time it was being sold in about 30 countries.

MMT had been most widely used in Canada, where it was used in roughly 90% of gasoline after the phase-out of lead was completed [Environment Canada, 2003]. Beginning in 1978, a series of safety reviews found no evidence that MMT would constitute a public health hazard. In 1994, Health Canada set a benchmark air level (below which no adverse health risks are expected) at $0.11 \mu\text{g}/\text{m}^3$ for respirable manganese, more than twice the reference concentration set by US EPA [EPA, 1994; NRTEE, 1999].

In 1996, in response to a petition by automakers claiming that MMT harmed pollution control equipment, Environment Canada announced its intention to restrict the use of MMT under a trade bill, Bill C-29 (the Manganese-based Fuel Additive Act). Ethyl responded by suing Canada for \$251 million under the North American Free Trade Act (NAFTA). In 1998, the ban was lifted and, in an out-of-court settlement with Environment Canada, Ethyl received \$13 million for “reasonable cost and profit” lost because of the bill’s implementation [National Roundtable on the Environment and Economy (NRTEE, 1999)].

Two separate reviews are being undertaken in Canada to consider the health and vehicle impacts of MMT and manganese. Health Canada has completed a review of the potential risk of manganese to human health and is in the process of undergoing external peer review. At the same time, Environment Canada is convening an independent third-party review of recent research findings on the vehicle and emissions impacts of MMT [Environment Canada, 2003]. Concerned about liability issues, the largest refiners in Canada voluntarily stopped using MMT in their gasoline pending the outcome of this review process [Inside Fuels, 2004].

The experience in the U.S. has been very difficult and contentious as well. In 1976, the California Air Resources Board (CARB) added a prohibition against the sale of unleaded gasoline with manganese additives to the California Code of Regulations. EPA also “approached cautiously” the use of MMT as a primary anti-knock replacement for lead [Moran, 1975] and, in 1977, the U.S. Congress added to the Clean Air Act (CAA) an amendment prohibiting use of manganese additives in unleaded gasoline unless EPA granted a waiver. During the phase-down of lead in the U.S., MMT continued to be used in leaded fuel but was not allowed in unleaded fuel.

The EPA denied several requests from Ethyl for a waiver to allow use of MMT in unleaded gasoline, based upon research showing that MMT use could impact emissions and emissions control systems. In 1994, EPA concluded that Ethyl had demonstrated that MMT would not “cause or contribute” to a failure of the emissions control devices used at the time [EPA, 1994]. EPA denied the waiver request, however, based upon the remaining uncertainty regarding the health impacts of MMT. The Ethyl Corporation sued EPA on a technicality and in 1995 was granted the right to market MMT for use in gasoline [EPA, 1995]. The U.S. Court of Appeals found that, under the specific CAA provision for the waiver, EPA could only consider emission factors and not health effects [National Roundtable on the Environment and Economy (NRTEE, 1999)]. The battle between Ethyl and EPA escalated further in March 1996 when Ethyl published full-page newspaper ads asserting MMT’s safety. Carol Browner, EPA Administrator at the time, issued a response stating, “The American public

should not be used as a laboratory to test the safety of MMT” [Browner, 1996].

While the U.S. federal government was forced in principle to allow MMT use in regular gasoline, the advocacy group Environmental Defense (then known as the Environmental Defense Fund) contacted all of the major oil companies in the U.S. urging them to avoid MMT use. In response, the major companies voluntarily disclosed that they were not using MMT and had no plans to do so [Halpert, 1996]. MMT use in the U.S. has increased slightly in the last few years and is now used by three small, independent refiners [Inside Fuels, 2004]. It continues to not be allowed in RFG sold anywhere in the U.S. and, 20 years after it was originally passed, the California ban on MMT was reviewed by CARB and upheld [California Air Resources Board (CARB, 1998)].

However, the same company that developed and produced leaded gasoline is now aggressively selling MMT, especially in the developing world, and the arguments in favor of such use and against restrictions have a very familiar ring—MMT is cheaper than alternative octane boosters, there is no evidence of adverse health impacts at levels to which the public would be exposed, and alternatives could be hazardous.

Beijing, China is a good case in point as it proposed a ban on MMT in early 2004. It immediately received a letter from Richard Wilson, formerly of EPA but then a consultant to Ethyl, providing a “balanced” view of the MMT issue [Wilson, 2004]. He offered several “personal thoughts in the hopes that they will be helpful” including:

- “EPA has the authority to regulate the use of MMT in gasoline if they believe its use causes health problems, but as of today no such action has even been proposed.” (Ignoring the ban in California and in reformulated gasoline).
- “Canada has had a successful program of MMT use for a number of years and Health Canada has concluded that ‘. . . MMT in gasoline powered vehicles is not entering the Canadian environment in quantities or under conditions that may constitute a health risk.’” (ignoring the Health Canada review which was already underway at the time).
- “Despite auto industry claims of adverse impacts on emission control systems, EPA has concluded that there was no such problem and the Canadian Experience has shown none.” (ignoring the Canadian announcement of the Blue Ribbon Panel to explore such claims and the fact that many vehicle manufacturers include warranty restrictions if MMT is used).
- “It is always possible that some new information will come to light that suggests the use of MMT should be regulated. But that is also true for all the other ways of increasing gasoline octane (I assume you are familiar

with the problems we have had with benzene, aromatics, MTBE, ethanol, etc.)”

He also failed to mention in this “balanced” overview, the statement made in 1996 by the Administrator of the EPA, when Ethyl pushed for the sale of MMT in the U.S. As noted above, she stated at that time when urging additional study and research, “the American public should not be used as a laboratory to test the safety of MMT” [Browner, 1996]. This resulted in a voluntary cessation in the use of MMT by major oil companies in the U.S.

CONCLUSIONS

The available information is beginning to illuminate the mechanisms by which manganese additives in gasoline could cause direct adverse health effects and damage to pollution control systems and if MMT were widely used as a gasoline additive, it could take decades, as occurred with lead additives, before the full health consequences were understood and agreed upon.

Considering the available information, the prudent course of action should be to stop the sale of MMT in gasoline until and unless further data show that Mn and its combustion byproducts will not result in adverse health effects and will not damage advanced vehicle pollution control technologies. Hopefully the lead experiment has taught us not to repeat it with another metallic additive without proof of safety.

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