Ethyl-leaded Gasoline:

How a Classic Occupational Disease Became an International Public Health Disaster

WILLIAM KOVARIK, PHD

The author describes the controversy about the use of tetraethyl lead (TEL) as a gasoline additive. Early warnings were ignored by industry, and as leaded gasoline became more profitable, scientists willing to support industry were financed as guardians of the scientific criteria for lead's health impacts. Controversy erupted in 1924 after refinery accidents left workers dying from violent insanity. In efforts to protect their profits, industry executives falsely claimed there was no alternative to leaded gasoline. Fifty years passed before scientific, court, and regulatory challenges had any influence. When independent research finally emerged, the results were damning enough to support an international phase-out of leaded gasoline. *Key words*: lead; gasoline; tetraethyl; public health; history; Alice Hamilton; Charles F. Kettering; Thomas Midgley; Yandell Henderson; DuPont, General Motors, Standard Oil, Exxon.

INT J OCCUP ENVIRON HEALTH 2005;11:384–397

Joseph G. Leslie, a chemical operator from Elizabeth, New Jersey, was dead. At least, that was what everyone was meant to believe. Only his wife Gertrude and later his son Joseph Jr. knew the truth: he had been badly injured at Standard Oil Company's Bayway, New Jersey, plant and was kept isolated in a psychiatric hospital for 40 years. When he actually died in 1964, the rest of the family was shocked to learn he had been put away, but no one understood the mystery. It took another 40 years for Leslie's descendants to begin putting the pieces of the puzzle together. Only in 2005 did they learn of a refinery accident that involved a strange case of severe lead poisoning and violent insanity among Standard Oil workers in a special section of the plant—the section where they made leaded gasoline.[1]

The confusion in the Leslie family's history reflects a larger picture of misinformation and deception in the history of environmental and public health. At the time when Leslie apparently went violently insane from lead poisoning, public health experts argued strongly for a permanent nationwide ban on leaded gasoline. Yet this vehement debate was so lost to history that when lawsuits over banning leaded gasoline were brought in 1974, none of the attorneys knew anything about it.[2] Even the court decision backing EPA's ban on leaded gasoline in 1976 said: "It is only recently that we have begun to appreciate the danger posed by unregulated modification of the world around us."[3]

The historical vacuum surrounding leaded gasoline was so complete that when the city of Chicago banned all sales of leaded gasoline in 1984, the *New York Times* said the ordinance was the first of its kind. In fact, the *Times* itself had covered city and state bans on leaded gasoline in the mid-1920s.[5,6]

These examples reflect a historical amnesia that is typical in the field of environment and public health policy, particularly so in this case. They also reflect the personal and social costs of having to repeat history when it is forgotten. Today, the public health argument for the elimination of leaded gasoline is widely accepted on an international level.[7,8] Yet historians have only recently begun to understand how and why leaded gasoline was introduced by the Ethyl Corporation, and its partners (General Motors, Standard Oil/Exxon, and DuPont).

U.S. historians have regarded the invention of ethyl-leaded gasoline as a heroic episode in the history of technology rather than a public health disaster that could have been averted. As recently as 1996, a biographical article about Charles Kettering mentioned the Bayway incident as a slight problem in Kettering's great inventive swath, omitting any reference to public health concerns or alternatives to leaded gasoline.[9] Other industrial historians have seen the discovery of leaded gasoline as exemplary. Researchers "tried out all elements possible in a so-called Edisonian style," said one leading historian.[10–13] Even public health historians who have documented the public health effects of leaded gasoline have tended to accept the idea that leaded gasoline was necessary and have not considered whether alternative technologies were available.[14,15] Since the existence of alternatives was a major point made by public health advocates in the 1920s, this author has argued for consideration of the issue.

Lead was first tried as an "anti-knock" additive for gasoline in 1921. Although other anti-knock additives were known, researchers at General Motors' (GM's) Dayton, Ohio, facilities believed that they could make more money with leaded gasoline. In 1923, Thomas Midgley calculated that it would be possible to capture

Address correspondence and reprint requests to: William Kovarik, 1408 Spring Street, Radford, VA 24141, U.S.A.; telephone: (540) 831-6033; e-mail: <wkovarik@radford.edu>.

20% of the gasoline market and make 3 cents per gallon, for about $36 million per year.[16] Within a decade the profits would be ten times that amount, and by the 1950s the profits would be in the billions. The crucial moment in making ethyl the dominant fuel came when GM and its part-owner DuPont joined forces with Standard Oil Co. (now Exxon) in August 1924 to market leaded gasoline through their partnership in the Ethyl Corporation (now New Market Corporation).

Controversy erupted in October 1924, when workers in a Standard refinery in Bayway, New Jersey, went violently insane after making leaded gasoline. Seven men died and 33 were hospitalized there; meanwhile, ten more were killed at a DuPont facility, and at least two died and 40 were hospitalized in Dayton, Ohio.[17–20] Leaded gasoline was the subject of a federal inquiry, but in 1926 the Public Health Service concluded that the dilute additive in gasoline posed no immediate threat to the public. Within a few years, nearly all gasoline contained lead.

In 1962, GM and Standard sold their interest in the Ethyl Corporation to a small group of independent investors.[21] A decade later, GM and the rest of the world's automakers began producing automobiles that used unleaded gasoline. By 1986 leaded gasoline had been taken off the market in the United States, and by 2000 it had been banned in Europe. Most developing nations are now phasing out leaded gasoline.

Lead as a Well-known Cause of Occupational Disease

Lead poisoning is one of the most frequently observed causes of occupational disease. From Roman antiquity through the industrial revolution, the cumulative effects of lead had become well known through painful experience. Roman engineer Vitruvius noted that lead fumes "rob the limbs of the virtues of the blood."[22] Romans consumed large quantities of lead to sweeten their food and wine.[23] Suspicion that lead caused the high incidences of gout, sterility, and infant mortality during the late Empire period has been common since at least the mid-19th century. In 1857, for example, *Scientific American* noted that sheets of lead had been used to sweeten winesince the Roman empire, but the practice had been abandoned because "all combinations of lead are decidedly poisonous."[24]

Bernardo Ramazzini, one of the first physicians to study occupational health, said around 1700 that: "The skin [of lead workers] is apt to bear the same color of the metal. . . . Demons and ghosts are often found to disturb the miners."[25] Printers were also frequent victims of occupational lead poisoning from handling and heating lead alloy type. In 1786, Benjamin Franklin noted the "mischievous Effect from Lead" but commented dryly: "You will observe with Concern how long a useful Truth may be known and exist before it is generally receiv'd and practic'd on."[26,27]

Lead's effects on industrial workers in the 19th and early 20th centuries were documented by writers and health professionals. Charles Dickens wrote about the terrifying effects of lead poisoning on London workers who could find no other employment.[28] Alice Hamilton, an MD who was known as the first woman admitted to the Harvard faculty, in 1919, made her reputation with a path-breaking study of occupational disease in Illinois.29 She found over 500 cases of outright lead poisoning and appalling conditions "equal to those described by French authorities of the early 19th century."[29]

The Development of Tetraethyl Lead as a Gasoline Additive

Despite the historical knowledge of lead's dangers, the automotive industry was interested in the metal's potential to prevent engine knock when used as a fuel additive. It raised what is now called "octane," which is the anti-knock property of gasoline measured by iso-octane reference fuel. The anti-knock power of 2–4 grams of tetraethyl lead (TEL) suspended in a gallon of gasoline was discovered December 3, 1921, at GM research laboratories in Dayton, Ohio. GM's vice president for research, Charles F. Kettering, was also president of the Society of Automotive Engineers at this time. Kettering and colleagues had engaged in a broad search for anti-knock fuel additives from 1916 to 1921 in order to improve engine compression and power. Division head Thomas Midgley had turned up many candidates and had met with a good deal of success in boosting anti-knock before leaded gasoline was discovered.[30]

Although lead was not the only additive or even technically the best additive Kettering and Midgley had found, it was cheap. A penny's worth would treat a gallon. Kettering gave leaded gasoline the name "ethyl," which confused the product with another fuel additive, ethyl alcohol, that was widely used in high-compression racing engines and in anti-knock blends with gasoline.[31] When laboratory tests of tetraethyl lead proved successful and business estimates looked promising, GM announced the discovery and began preparing to market leaded gasoline.[32]

A flurry of correspondence between GM and the public health community preceded the public controversy by two years. Warnings about the danger of leaded gasoline came directly to Midgley and Kettering from Robert Wilson of MIT, Reid Hunt of Harvard, Yandell Henderson of Yale, and Charles Kraus of the University of Pottsdam in Germany. Kraus had worked on tetraethyl lead for many years and called it "a creeping and malicious poison" that had killed a member of his dissertation committee.[17] In addition to the private warnings, an official letter from the U.S. Public Health Service asked whether leaded gasoline might not be a "serious menace to public health." Midgley responded that the problem "has been given very serious consid-

Figure 1 An artist's depiction of a lead-poisoned worker, New York Journal, October 31, 1924, page 2.

eration . . . although no actual experimental data has been taken."[33]

In public, leaded gasoline was portrayed as a breakthrough, and in December 1922 Midgley was awarded the prestigious William H. Nichols Medal from the New York section of the American Chemical Society.[34] Thus, without safety research but with support from the chemical industry, leaded gasoline was introduced on the market in February 1923. Motorists liked the extra boost the gasoline gave, and GM and DuPont joined Standard Oil Co. of New Jersey (now Exxon/Mobil) in a joint venture to create the Ethyl Corporation in 1924.[35]

The biggest problem at this point was that the manufacturing process for TEL was not safe, a DuPont report later acknowledged.[17] Reactor vessels were not closed off to workers but were configured for batch processing and had to be opened between stages of the process. Agitating elements were recovered by squeezing semi-molten lead between grates with shovels and boots. Inevitably, refinery workers were routinely exposed to highly concentrated lead vapor.[36]

Seven workers died between September 1923 and the fall of 1924 in GM's Dayton, Ohio and DuPont's southern New Jersey factories, but no one outside the Ethyl partnership understood the significance of these apparently disconnected industrial accidents.[17] Then, as Standard Oil started up a new and even more hazardous TEL refining operation in northern New Jersey, five workers died in one week from lead poisoning so severe that it was not initially recognized by occupational health experts.[37]

PUBLIC CONTROVERSY OVER LEADED GASOLINE

> "These men probably went insane because they worked too hard."[37]

The public controversy began October 27,1924, when what seemed to be a mysterious gas began poisoning workers in the new section of the Standard Oil refinery near Elizabeth, New Jersey, just across the river from New York City. Several workers had to be subdued and put into straightjackets. They were black and blue from uncontrolled muscle spasms. They exhibited paranoid and delusional behavior such as cringing from phantoms or snatching at imaginary winged insects. The afflicted workers could be suddenly violent or suicidal. They also had blue lines across their gums, a typical indicator of lead poisoning, but the behavioral symptoms were unlike any presented in previous lead-poisoning cases. When the first worker died in the hospital, writhing in agony, a horrified county medical examiner called the district attorney, who began an investigation. This alerted the news media, and on October 27, accounts of the odd new kind of occupational hazard were carried on the front pages of newspapers around the world.[37] Figure 1 shows a contemporary illustrator's depiction of the effects of lead poisoning.[38]

Standard Oil had no official comment at first, although one refinery supervisor, later reported as suffering from lead poisoning, famously said: "These men probably went insane because they worked too hard." Workers at the refinery, however, knew that the exposure to lead vapor was dangerous, and they called TEL "loony gas." Workers also dubbed the Du Pont refinery the "house of butterflies" because of the typical delusions of winged insects that affected many of the workers.[20]

Yale professor Yandell Henderson, a leading expert on the effects of gas warfare and automobile exhaust, told newspapers that the mystery gas was called "tetraethyl lead," and it was "one of the most dangerous things in the country today." Henderson knew about TEL because he had refused an offer to study it for GM, saying "I should want a greater degree of freedom of investigation and funding—in view of the immense public, sanitary and industrial questions involved—than the subordinate relations which you suggest would allow."[34] He found the idea of TEL in gasoline alarming. A car with problems on Fifth Avenue could, he told the news media, "release a quantity of gas . . . (and) cause gas poisoning and mania to persons along the avenue." The person might not even know until it was too late because there was no odor and the symptoms would be delayed.*[18]

W. G. Thompson, chairman of the Ethyl partners' medical committee, said Standard "has given a great deal of attention to safety measures and no expense has ever been spared to safeguard employees against illness or accidents."[39] However, at the time, many company engineers would not have agreed with this statement. "The extremely hazardous nature of TEL was already well known to GM, DuPont, and Standard Oil," a confidential DuPont report said. For example, when a delegation of DuPont engineers visited the Standard refinery in September 1924, they found safety precautions being taken at the Standard refinery to be "grossly inadequate."[17]

By October 30, 1924, with the known death toll at five, GM's fuel research chief Thomas Midgley was introduced to a press conference at Standard headquarters at 26 Broadway. To impress the journalists, Midgley poured a thick stream of a clear liquid over his hands and then dried it off with a handkerchief.[6] Then he held a bottle of liquid under his nose for a minute and he "insisted that the fumes could have no such effect as was observed in the victims if inhaled only a short time." Midgley insisted the injuries were "caused by the heedlessness of workers in failing to follow instructions" rather than by the danger of the poison itself.[6]

The news media was openly skeptical. Reporters asked Midgley whether it was true that other workers had been hospitalized and had died in Dayton, Ohio. He admitted two deaths had occurred in April 1924, and that over 50 workers had been "under observation" for the effects of lead poisoning. He acknowledged that the DuPont corporation had also had "similar problems." But he insisted, as did other officials, that TEL was safe for normal use. "This extremely dilute product has been for more than a year in public use in over 10,000 filling stations and garages and no ill effects thus far have been reported."[40]

Standard and GM continued to insist that every precaution had been taken to protect workers and insinuated that the workers who had died had been negligent. They said the "mystery gas" was merely "ethyl," which was nothing new to science. They insisted that it was safe for motorists because it was diluted. And they said that Standard, GM, and DuPont were simply trying to improve the efficiency of automobiles.[19]

GM also told the government that the time had come to issue the report on the safety of leaded gasoline. The U.S. Bureau of Mines had conducted experiments for GM on animals exposed to exhaust from engines running on leaded gasoline with the express contractual arrangement that the result and the timing of their release would be controlled by GM. On October 31, 1924, the Bureau issued its report. "The danger of sufficient lead accumulation in the streets . . . [is] seemingly remote."[41,42] Public health scientists, especially Alice Hamilton of Harvard, were critical, noting that the bureau had kept the animal cages well ventilated and had not allowed lead dust to accumulate.[43] Hamilton also wrote to Surgeon General Hugh Cumming that GM funding for the study "will in the eyes of Labor always serve to cast doubt on any negative results obtained by the investigators. . . ."[44]

Despite the public relations efforts, the New Jersey Labor Commission shut down the Bayway refinery in early November, and a Union County prosecutor started a grand jury investigation (it ended in February 1925 with no charges filed). Sales of leaded gasoline were banned in New York City, Philadelphia, and New Jersey.[17] While Standard, GM, and DuPont maintained a brave external posture, an internal controversy raged. "They were in a blue funk over the whole thing, and the directors were very much afraid about it," Kettering said some years later. "They didn't know what was going to happen to them."[45] A GM attorney summed up his company's animosity toward Standard by saying: "They put up a plant that lasted two months and killed five people and practically wiped out the rest of the plant."[45]

The public side of the debate continued into 1925 with dozens of major newspaper articles and columns appearing mostly in the two leading New York newspapers, the conservative *Times* and the liberal *World*. The contrast in news coverage is interesting: the *Times* quoted industry sources 30% more often than the *World*, while the *World* quoted university scientists 50% more often than the *Times*.[46]

Industrial scientists rallied to the defense of leaded gasoline. Harrison E. Howe, editor of the journal of the American Chemical Society, said within one month of the New Jersey deaths that it would be "folly" to discontinue the use of a substance that would help conserve petroleum. While the public might be concerned about small amounts of lead in gasoline, Howe said, a far greater concern was felt by manufacturers "who realize to what extent they would be the subject of attack should it develop that the public is endangered by the use of this fuel."[47] A few months later, the American Chemical Society would back away from Harrison Howe's support for ethyl, saying that the idea of increased government regulation over chemicals "is a subject worthy of further discussion."[48]

The *New York Times* agreed with Howe in a November 28, 1924, editorial, saying the deaths at the Standard refinery were

*Severe lead poisoning from full strength TEL tends to have a gradual onset, as Henderson implies here. However, Henderson also believed that GM was marketing autos with two fuel tanks, one using full-strength TEL. GM abandoned this plan sometime in late 1922 and began marketing TEL in 1923 by blending it with gasoline at the service station pump. This also created localized cases of lead poisoning, and in late 1924 GM ordered the mixing to be done higher up the fuel stream at bulk distribution plants.

> not a sufficient reason for abandoning the use of a substance by means of which a large economic gain could be effected—that is, a considerable increase in the value of gasoline as a source of power. . . . As there is no measurable risk to the public in its proper use as a fuel, the chemists see no reason why its manufacture should be abandoned. That is the scientific view of the matter, as opposed to the sentimental, and it seems rather cold-blooded, but it is entirely reasonable. The making of explosives is not stopped merely because it necessarily is a dangerous industry, and nobody suggests that the building of airplanes should cease, though every flight is at some risk of life.[49]

At the same time, public health experts insisted that lead was an historically well-known poison. "For 100 years and more, observations have been made as to the effect of having a noteworthy amount of lead dust around in any occupation," said David Edsall of Harvard. "It is not a question, then, whether there is or is not a hazard."[50]

The controversy shows how sharply the lines were drawn between industrial chemists and engineers on the one hand and doctors and public health experts on the other. Ethyl, GM, Standard, and DuPont claimed in public that they could not have foreseen the effects on workers, and yet they had been strongly warned in private correspondence and discussions with scientists and fellow engineers many times before the refinery disaster.

DECEIT ABOUT ALTERNATIVES

With the American Chemical Society acknowledging that government regulation of industrial chemicals was a topic that should be on the table, Ethyl needed a stronger argument than good intentions or a general view of scientific progress to maintain control of a profitable product. Officials with GM, DuPont, and Standard Oil—now partners in Ethyl—began to argue that there were no substitutes for or alternatives to leaded gasoline. Thomas Midgley told an American Chemical Society meeting in April 1925:

> So far as science knows at the present time, tetraethyl lead is the only material available which can bring about these [anti-knock] results, which are of vital importance to the continued economical use by the general public of all automotive equipment. . . .[51]

This argument was central to industry's position at a May 20, 1925, conference called by the Public Health Service in Washington D.C. Over 100 industry and public health representatives attended, including Alice Hamilton, Yandell Henderson, and Charles Kettering.

Once again, Ethyl's main defense was the lack of alternatives to leaded gasoline. Kettering said: "With ordinary natural gas we could produce certain [anti-knock] results and with the higher gravity gasolines, the aromatic series of compounds, alcohols, etc., we could get the high compression without the knock, but in the great volume of fuel of the paraffin series we could not do that."[50] No one asked Kettering just why the industry could not do that, or even why other compounds could not be added to the great volume of the fuel. Standard Oil's Frank Howard was even more adamant: "Present day civilization rests on oil and motors. . . . We do not feel justified in giving up what has come to the industry like a gift from heaven on the possibility that a hazard may be involved in it.[51]

Historians concerned with public health and lead toxicology have taken these assertions at face value. For example, a 1986, a textbook on lead toxicology said: "To this day, no cost-effective alternatives to lead as an anti-knock additive have been discovered. . . ."[52] Similarly, historians Rosner and Markowitz observed in 1989 that tetraethyl lead "allowed for the development of the automobile essentially as we know it today."[14]

In contrast, public health experts in the 1920s insisted to news reporters that alternatives were available and perfectly obvious. In covering the May 1925 PHS conference, the *New York Times* quoted Alice Hamilton as she "urged the men connected with the industry to put aside the lead compound entirely and try to find something else to get rid of the knock."[51] Hamilton also told Kettering directly that there were "thousands of things better than lead to put into gasoline."[34] And the *World* quoted her as saying " Men who could discover the fuel value of tetraethyl certainly could invent or discover something equally efficient and in no way dangerous."[53]

The question of alternatives loomed large and may have threatened GM and Standard Oil. The *World* account said:

> Original plans had called for presentation to the Public Health conference of claims of various persons that they have discovered dopes [additives] for fuels which are as efficient as lead but lack the danger. The conference decided at the last minute, however, that such things were not in its province. . . . For this reason, the conference adjourned after only a one day meeting, where it had been thought at first that four or five days might be taken.†[53]

Kettering's lack of experience with the history of lead poisoning, his lack of compassion for workers who had been killed making TEL and especially his technological determinism all grated on Alice Hamilton. In a hallway confrontation during a break from the PHS conference, Hamilton told Kettering "You are nothing but a murderer." GM researcher T. A. Boyd witnessed

†PHS was a division of the Dept. of the Treasury, and Andrew W. Mellon, a major owner of Gulf Oil. Co., was Secretary of Treasury. Gulf had a contract for TEL treatments for 11,162,400 gallons of gasoline in effect at the time.

the scene and later wrote in an unpublished memoir about the fire in Hamilton's eyes and the bite in her words. According to Boyd, Hamilton said: "Why, there are thousands of things better than lead to put in gasoline." Kettering answered her with the detached amusement that colleagues admired but Hamilton must have found grating: "I will give you twice your salary if you will name just one such material." Hamilton apparently responded, "Oh, I wouldn't work for you."[34]

The alternatives that Kettering dismissed so lightly in public were taken far more seriously in private. Sun Oil Co. was marketing a blend of gasoline from high-aromatic crude petroleum with butyl alcohol additives. Arco was marketing a "white flash" blend with benzene (often called "benzol"). Thermal cracking for better-octane gasoline had been introduced around this time, and catalytic cracking would be adopted in refineries a few years later.[54] Even many of Ethyl's early advertisements stressed competition with alternatives. ("We sell the new Standard 'Ethyl' Gasoline already mixed and thoroughly filtered as well as the "Standard Benzol," Standard straight and Texaco straight gasoline.")

Another alternative, ethyl alcohol, produced an anti-knock effect identical to that of ethyl when blended in 10–20% volume with gasoline. Such blends were well known in Europe and Latin America. Figure 2 shows a British advertisement for such a fuel, circa 1935. Even a 1915 children's book of the future of engineering, entitled *Modern Inventions*, had a chapter devoted to "Alcohol Motors and the Fuel of the Future" sandwiched amid the zeppelins and submarines.[56] Two years later, in *National Geographic*, famed telephone inventor Alexander Graham Bell challenged other would-be inventors to develop methods to deal with eventual oil and gas depletion by adapting machinery to ethyl alcohol fuel.[57]

> Alcohol makes a beautiful, clean and efficient fuel, and, where not intended for consumption by human beings, can be manufactured very cheaply. . . . Alcohol can be manufactured from corn stalks, and in fact from almost any vegetable matter capable of fermentation. Our growing crops and even weeds can be used. The waste products of our farms are available for this purpose and even the garbage of our cities. We need never fear the exhaustion of our present fuel supplies so long as we can produce an annual crop of alcohol to any extent desired.

Scientific American followed fuel research very closely during this period, and published many articles such as these representative samples from 1918–1920:

> . . . the fuel problem is rapidly getting more serious… It has been found that a mixture of 25 percent each of gasoline and benzole [benzene] with 50 percent of alcohol works very satisfactorily in our present motors, and . . . this may prove to be the solution of the fuel problem."[58]

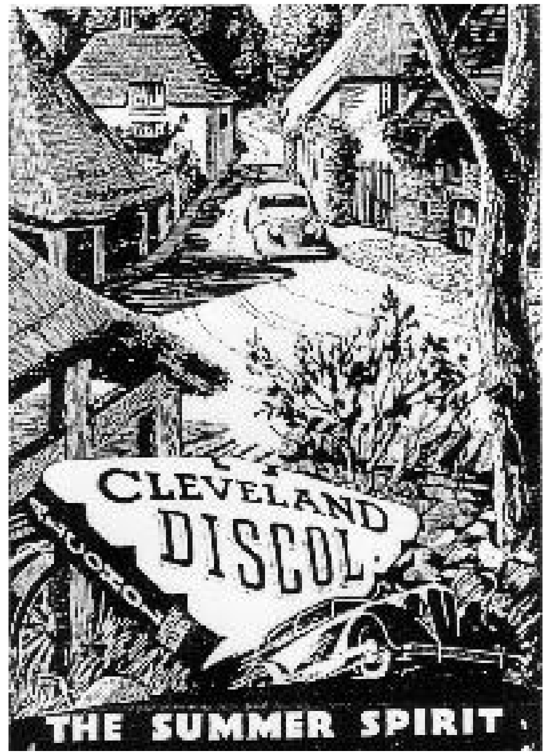

Figure 2 An advertisement for an alcohol fuel blend in England, around 1935.

> It is now definitely established that alcohol can be blended with gasoline to produce a suitable motor fuel that will avoid the difficulties of starting a cold motor on alcohol alone and without any change in the carburetor or the compression of the engine. . . . The production of industrial alcohol on a large scale would accordingly help materially to increase the supply of fuel. . . . Distilleries and breweries whose business is being curtailed by passage of 'dry' laws in different states . . . should welcome an opportunity to continue operation.[59]

> Patent . . . specifications bear evidence of the universal assumption that [ethyl] alcohol in some form will be a constituent of the motor fuel of the future. . . . Every chemist knows [alcohol and gasoline] will mix, and every engineer knows [they] will drive an internal combustion engine.[60]

This fuel of the future was so well known as an anti-knock that a Commerce Department report printed a week before the PHS conference in 1925 noted that it was used routinely in two dozen other industrial nations.[61] This fuel was also safer than either leaded gasoline or alternative anti-knock compounds such as blends of benzene and gasoline.

Even if alternatives were widely known in general, a key question is whether Kettering, Midgley, and others in the Ethyl partnership knew about alternatives themselves. Private corporate memos clearly show that GM and Standard officials discussed the alternatives frequently. Although Kettering, Howard, and Midgley told the Public Health Service conference that there were no options, they had studied ethanol as one of the best anti-knock fuels from the beginning of their research in 1916.[62] In a 1922 Society of Automotive Engineers (SAE) paper approved by Kettering, Midgley noted that alcohol, benzene and other aromatic hydrocarbons had been "known for some time" as reducing the tendency of gasoline to knock. Midgley even acknowledged that there was "extensive use" of alcohol for motor fuel in other countries.[63,64] In internal memos within the lab, Midgley noted that alcohol was "of course, the fuel of the future."[65]

At one point in 1920, Midgley sent lab assistant T. A. Boyd to study cellulose conversion to ethyl alcohol fuel with Prof. Harold Hibbert at Yale University. Hibbert was a visionary, who noted oil reserves might soon be depleted. "Does the average citizen understand what this means?" he asked. "In from 10 to 20 years this country will be dependent entirely upon outside sources for a supply of liquid fuels . . . paying out vast sums yearly in order to obtain supplies of crude oil from Mexico, Russia and Persia." But the chemist might be able to solve the problem, Hibbert said, by working on abundant cellulose waste from farm crops, timber operations and seaweed as a source of ethyl alcohol.[66] But Boyd said he found Hibbert's work confusing, and Midgley pulled him away when it looked as if many months of study would be needed.[34]

Concern about alternatives is evident in GM and DuPont memos both before and after the Bayway incident. In 1923, Irenee DuPont wrote DuPont's technical director, W. F. Harrington: "It is essential that we treat this undertaking like a war order so far as making speed and producing the output, not only in order to fulfill the terms of the contract as to time but because every day saved means one day advantage over possible competition. . . ."[34] In 1925, just a few months after the PHS conference where GM and Standard claimed there were no alternatives, the head of Standard Oil wrote to Kettering about new gasoline-refining technologies, new sources of higher-octane crude oil, and other fuel blends in competition with Ethyl leaded gasoline. "Benzol (benzene) blends are, of course, in another category," Howard said, ". . . equal or superior of Standard Ethyl Gasoline in knock rating." Howard also said that Standard's benzol blend was so well established in the Baltimore–Washington territory that they could not replace it.[67] In 1928, Sloan requested a report on alternatives to ethyl. In 1931, Boyd wrote yet another memo that identified alternatives.[68]

Thus, there was no truth to the claim that alternatives to leaded gasoline did not exist, even to a generous interpretation that perhaps Kettering and Midgley were not aware of them. Moreover, alternatives played an important role in GM's long-term planning. A DuPont legal history of ethyl-leaded gasoline written in 1936 noted that "an important special motive" for the original tetraethyl lead research and development was GM's desire "to fortify itself against the exhaustion or prohibitive cost of the gasoline supply, which was then believed to be impending in about twenty-five years; the thought being that the high compression motors which should be that time have been brought into general use if knocking could be overcome could more advantageously be switched to [ethyl] alcohol."[17]

In other words, TEL was originally seen as a bridge to help adapt engines to switch to alternatives when oil ran out, which was predicted as imminent by the U.S. Geological Survey, among others.[69] But the market power of Standard Oil and the opening of new oil reserves in the late 1920s soon put an end to Kettering's vision of an auto industry running on non-petroleum fuels. Years after the controversy, Kettering's friend Charles Stewart Mott noted "that if a time ever came when the sources of [fossil] heat and energy were ever used up . . . that there would always be available the capturing of . . . energy from the sun . . . through agricultural products. . . ."[70] This distant recollection would be all that remained of the original special motive for creating leaded gasoline.

HEGEMONIC SCIENCE

The 1925 Public Health Service conference resulted in the appointment of a panel of six medical experts from Harvard, Yale, Johns Hopkins, Vanderbilt, the University of Chicago, and the University of Minnesota. The committee began work in June 1925 and in the fall, reviewed a PHS-sponsored study of workers exposed to TEL in garages and filling stations in Cincinnati and Dayton. The two studies found some "stippling" damage to red blood cells but no obvious external signs of clinical lead poisoning in muscle strength or gum color.[71]

The question of general environmental exposure was based on an Ethyl lab test finding that 70% of the lead in a gallon of gasoline "must have remained in the engine" because it could not be measured in the exhaust. Of the remaining 30%, half was accounted for in the engine crankcase oil.[72] Using these figures, committee member Reed Hunt of Harvard made a "very tentative" estimate that average daily exposure to lead from auto traffic would be about 0.02 micrograms of lead per cubic meter of air and noted that 0.5 to 1 mg of lead per cubic meter was considered to be the occupational threshold for lead poisoning.‡[73]

‡Hunt originally calculated 0.5 mg/m^3 but noted that Graham Edgar of Ethyl showed that only 4/5 of the lead from the explosion left the engine. He also noted that Thomas Legge, Chief Medical Inspector of Factories in the U.K. at the time, put the exposure figure at 2 mg/m^3 as the minimum occupational exposure causing plumbism. [In contrast, the 1961 survey finding from 1.4 to 25 mg/m^3 to be typical of atmospheric lead concentrations on the streets of Cincinnati and Los Angeles—over 100 times higher than Hunt's estimate 35 years later.]

Since Hunt's miscalculation was not based on any independent observations of actual street-level contamination, it would not have surprised some of the more skeptical committee members that concentrations were found to be far higher when independent studies were finally performed in the 1960s.[74,75] The miscalculation seems obvious today—after all, the lead does not just disappear in the combustion process, and Edgar's research engine was run only for 1,000 hours. The storage of lead would have taken place only in the initial phase of research, as Edgar must have known. Yet the committee was under pressure to conclude its work within a matter of a few months, and some members were apparently predisposed towards industry. The committee report of January 1926 said that there appeared to be "no good grounds" to ban leaded gasoline for the time being. However, the committee was not entirely satisfied:

> We are conscious of the fact that the conclusions to which we have come in this report . . . are subject to criticism on the grounds that that they have been derived from the study of a relatively small number of individuals . . . who were exposed to the effects of ethyl gasoline for a period of time comparatively brief when we consider the possibilities in connection with lead poisoning. . . . It remains possible that if the use of leaded gasoline becomes widespread, conditions may arise very different from those studied by us which would render its use more of a hazard. . . . Longer exposure may show that even such slight storage of lead as was observed in these studies may lead eventually in susceptible individuals to recognizable lead poisoning or chronic degenerative disease of obvious character. . . . The committee feels this investigation must not be allowed to lapse.[71,77]

C. E. A. Winslow, of Yale, also recommended that the "search for and investigation of antiknock compounds be continued intensively with the object of securing effective agents containing less poisonous metals (such as iron, nickel, tin, etc.) or no metals at all."§[78] Winslow must have been thinking of information he had received about alcohol as a fuel from GM's competition, the Ford Motor Co. "Alcohol is reported to be produced for between 10 cents and 20 cents per gallon and has much promise as a mixture with hydrocarbon fuels to eliminate knocking and carbonization," Ford wrote Winslow.[79] In any event, neither of the research recommendations was heeded.

Lead Industry Funds Research

While independent research stalled for the next 40 years, the lead industry began funding its own research in 1925, through Dr. Robert Kehoe, who was simultaneously a professor of physiology at the University of Cincinnati and director of the (Charles) Kettering Laboratory, as well as the medical director of the Ethyl Corporation. The character of Kehoe's research would become a subject of considerable controversy in the 1960s.

Kehoe's theory was that some amount of lead in the body was natural. "During the entire history of man on this earth he has had lead in his body. He has had lead in his food, he has had lead in his drinking water. . . . The question is not whether lead per se is dangerous, but whether a certain concentration of lead in his body is dangerous."[80] Lead in the body was so natural that it "went back to Adam," Kehoe often said.

Kehoe developed four theses about lead: 1) that lead absorption is natural; 2) that the body has mechanisms to cope with lead; 3) that below a certain threshold, lead was harmless; and 4) that the public's exposure was far below the threshold and was of little concern.[81] Thus, according to Kehoe, lead in the body was not proof of industrial contamination but rather that the person was living within the normal "lead bearing" environment. The human body established an "equilibrium" between lead intake and lead elimination. "Far more lead is taken into the body from food, water and other beverages than from the air . . . lead intake from food and drink averages on-third of a milligram a day, while intake from breathing is as little as one-twentieth of that amount."[82,83]

Kehoe's research on human subjects attempted to define a threshold at which lead would be detectable during a physical examination. Subjects ate or breathed set amounts of lead for months or sometimes years.[80] It was this research that established the 80 micrograms/ deciliter (µg/dL) threshold for adults and 60 µg/dL for children at which noticeable clinical symptoms would emerge. These blood levels remained the diagnostic criteria for lead poisoning until 1980, when OSHA changed the standard for worker medical removal to 70 and then 60 µg/dL.[84]

Still, the idea of a threshold for effects remains a problematic concept. Workers in the lead industries would reach an exposure level and then be subjected to dangerous blood-chelation therapies. Their blood lead levels would be reduced and they would return to work, only to go through the same cycle later.

From the 1920s to the 1960s, Kehoe helped the lead industries use their economic power to define the scientific basis of lead poisoning. Historians such as William Grabner, Christian Warren, David Rosner, and Gerald Markowitz have noted that Kehoe and the Kettering laboratory were able to translate industry's needs into the language of science through the creation, funding, and control over publication of lead-related research. "So complete was the industry domination of research into and knowledge of the hazards of lead," said Grabner, "that the central paradigm for

§Winslow had been engaged in an extensive investigation of alternatives and reported them to the committee, but this correspondence is missing from the federal archives.

understanding lead and its effects remained that pioneered by Kehoe and his associates."[81,85] One PHS official noted that it is "extremely unusual in medical research that there is only one small group . . . in which research is exclusively done."[80]

It's interesting that the lead-equilibrium theory may have originated with Thomas Midgley, the developer of TEL at GM who originally hired Kehoe. In an oral history, Standard Oil president Frank Howard recalled:

> Midgley from the outset . . . pointed out the obvious truth that we were all exposed to lead in our environment at all times. I remember Midgley telling me about the lead content of the city water in Dayton and every place else one could think of. . . . It was in fact a question of the balance of lead intake and lead output. . . . These facts were so simple and obvious that they seemed to us at the time to settle the problem and provide an answer to the hysteria.[86]

EXPOSING LEAD'S SCIENTIFIC CAMOUFLAGE

Air-pollution incidents in the post-WWII era in Donora, Pennsylvania, Los Angeles, London, and New York[87] awakened interest in all kinds of public health issues, including leaded gasoline, although the original TEL controversy and knowledge of alternatives had long been forgotten. General Motors and Ethyl kept close track of air-pollution controversies, especially in California, where most air pollution was blamed on automobiles rather than factories. Research reports from the Air Pollution Foundation, an ostensibly independent group, noted that it would be prohibitively expensive to replace lead or to use catalytic converters or alternative fuels.[88] But the writing was on the wall by in 1961, when a PHS study of Los Angeles, Cincinnati, and Philadelphia found high levels of lead in the local air samples—from 1.4 to 25 mg/m^3, and high blood lead levels in many test subjects.[89]

Lead Contamination and Clair Patterson

Around the same time, a CalTech geophysicist named Clair Patterson was attempting to estimate the age of the earth and the solar system by studying the rate of uranium decay in samples of meteorites. Uranium decays into lead, and Patterson originally thought it would be easy to measure the ratio of lead in samples and make the estimate. He found, however, that a new and much more difficult method for controlling laboratory contamination was necessary because lead was so abundant in everyday life—in clothing, in the air, in the water, even in his own hair. Using strict controls, he found that previous studies had confused the preindustrial background level of lead with typical modern levels due to contamination. Patterson became convinced that modern exposures were harmful.[90]

In 1965, Patterson published an article in *Archives of Environmental Health* stating that the atmosphere of the northern hemisphere contained 1,000 times more than the natural amounts of lead. Patterson could have safely stopped with this finding, but instead he ventured from his narrow discipline to point out the broad public health implications of his research. He said that the abundance of lead in the environment showed that people were being subjected to "severe chronic lead insult." He especially attacked Kehoe's concept of a threshold for damage as " an ill-defined opinion unsupported by any evidence."[91]

Not surprisingly, Kehoe was among the peer reviewers who commented on the paper before it was published. He wrote that the paper was "an example of how wrong one can be," Not only was Patterson "woefully ignorant," but he was also unaware of the depth of his ignorance. Perhaps believing himself magnanimous, Kehoe decided the journal should welcome the article's appearance because the conclusions were so wrong they should be "faced and demolished."[92]

Kehoe got his chance to face and demolish Patterson in the summer of 1966, when lead poisoning became the central subject of a set of hearings by a newly formed Senate Environment Committee chaired by Sen. Edmond Muskie. Kehoe, at the end of his career, was the star witness. Senators questioned him about the toxic effects of lead and about the availability and desirability of alternatives to leaded gasoline. Kehoe maintained that his extensive investigations had shown "definitive results" that leaded gasoline was not a public health problem and therefore no alternatives, if any actually did exist, need be considered.¶[93] Clair Patterson was the other star witness. He discussed the *Archives* article and attacked government agencies. "It is not just a mistake," he said, "for public health agencies to cooperate and collaborate with industries in investigating and deciding whether public health is endangered—it is a direct abrogation and violation of the duties and responsibilities of those public health organizations."[94]

Patterson's stand cost him his research funding and very nearly his job, as members of the CalTech board of visitors who worked for the oil industry pressured his dean to let him go. But his research was meticulous and his conclusions, when reviewed, were found to be valid. Support came from other sources, allowing work with Arctic ice cores and deep sea sediments that confirmed the original findings that far more man-made lead was found in upper layers of ice and ocean than in the layers deposited before the industrial revolution.[92]

¶That Kehoe could question whether alternatives existed in Senate testimony showed how little was known of the subject. In a stipulation to an antitrust lawsuit brought in 1937, Ethyl had said "high anti-knock values may be and are also obtained by the addition to gasoline of benzol and alcohol . . . while the use of alcohol is relatively new in the US, it has been used extensively abroad for many years."

Occupational and Pediatric Lead Poisoning and Herbert Needleman

Once an understanding of the geophysical dimensions of the problem was achieved, the question became one of understanding the apparent gap between Kehoe's threshold level and health impacts at lower levels. Industry continued to insist there were no ill effects below 80 µg/dL and labor resisted factory air monitoring because "it allowed industry to blame workers' personal hygiene practices for any elevated blood lead levels," according to historians David Rosner and Gerald Markowitz.[15] Industry argued against higher standards on economic grounds as well.

With more precise blood-measurement technologies and epidemiologic tools, it was no longer possible to dismiss the questions about subclinical effects as being based on inexact, unproved, and unprovable scientific reasoning. The definition of occupational lead poisoning had changed from Kehoe's 80 µg/dL to a level of 60 µg/dL by 1980, even though health effects have been found at 30 µg/dL. The allowable level of lead in workplace air, for example in foundries, was also reduced in the 1982–1989 period from 200 mg/m^3 to 50 mg/m^3.[15,84] A greater change was the definition of lead poisoning in children, beginning in 1972 with a standard set by the Surgeon General at 40 µg/dL, then revised downward to 25 µg/dL in 1985, then 15 µg/dL in 1990, and shortly thereafter 10 µg/dL.[81] Despite an assault in the Reagan administration's era of deregulation, the standard held.

Behind these incremental changes was a sea change in the perception of risk in the lead-poisoning debates. Until the 1970s, nearly all the research on lead poisoning was focused on adults and aimed at avoiding occupational plumbism. But children came to be recognized as more vulnerable in their developmental stages to neurologic damage from lead poisoning. It was also recognized that children were exposed to leaded gasoline from the atmosphere and soil. Measuring lead in children, however, had been a problem for decades. In 1943, Randolph Byers found that 20 children with lead poisoning had behavior problems. Lead industry officials approached Byers "in an effort to muzzle his message" with a research support offer and, when he refused, a corresponding threat of a lawsuit. The research work did not continue.[81]

In 1974, psychiatrist Herbert Needleman and colleagues found that teeth made better markers of past lead exposure than the blood samples that had been relied upon in the past. They collected teeth from 2,500 primary school children. After controlling for other confounding variables such as socioeconomic status, they found that as lead levels increased, all measures of school performance decreased significantly.[95] Needleman's pediatric work in the 1970s was duplicated by others around the world, but meanwhile, in 1982, a scientist working with the lead industries accused Needleman of manipulating his scientific data to create a false impression that lead was toxic. The accusations were eventually dismissed by an EPA science advisory council and the EPA confirmed Needleman's work as a pioneering study.[14]

Another attack took place through a National Institutes of Health inquiry in 1991. The suggestion for the investigation originated in the law offices of a firm representing Ethyl. Needleman's methods and conclusions were vindicated, but the experience itself was harrowing. "We have seen how the process of controlling scientific misconduct itself can be bent to harass these investigators," Needleman said. "If this can be attempted with established investigators, what are the effects upon less secure junior scientists who are thinking about studying the toxic effects of some commercial product."[92] Even as late as 2005, Needleman's work was the subject of what some saw as unfair attacks in the context of a lead paint lawsuit.□

These attacks were among many ways that the lead industry attempted to obscure the mounting evidence of public health damage from lead. The lead industry funded research to show that lead is an essential trace element in the human body. Investigators with the lead industry criticized human lead studies as not controlling for all possible variables. They also criticized animal studies, arguing that the findings could not be extrapolated to human beings.[81] For example, the responses to Patterson's article in the *Archives of Environmental Health* challenged even the most basic decision to publish the findings.[96] This, then, was the Kehoe paradigm for ensuring the longevity of profitable poison—attack, question all research as ultimately imperfect, and maintain all the while that the burden of proof must fall on public health advocates and not on industry.

The hegemony over scientific evidence involved "professional ties in the medical establishment and the persuasive influence of lucrative grants," said historian Jerome Nriagu,. "A network was established which successfully excluded from the scientific literature and professional reports any negative opinion pertaining to the hazards of lead to the general public." Many public health watchdogs, such as the American Medical Association, the American Public Health Association, and the U.S. Public Health Service, were led into a mode of thinking and a web of professional obligations which effectively excluded independent analysis.[97]

LEADED GASOLINE PHASE-OUT

When debate over the safety of TEL resumed in the 1960s, it was far from clear that an actual phase-out of

□In *Rhode Island v. Lead Industries Association et al.* discovery process, industry requested complete sets of raw data from research that had already been peer reviewed.

TEL would be technologically or politically possible. However, strong public pressure to clean up the nation's air and water led to the Clean Air Act of 1970. When it was passed in December 1970, the act mandated a 90% reduction in three major emissions: carbon monoxide, nitrogen oxides, and other hydrocarbons (mostly unburned fuel).[98]

The best way to do that, according to GM, was to use an exhaust-system device called a catalytic converter. Lead would have to be taken out of gasoline because it ruined the platinum surfaces of the catalytic converter. GM had been working on catalytic converters for at least four years when it sold its interest in Ethyl to a small Virginia paper company in 1962, and it would take another dozen years to begin producing cars that were designed for unleaded fuel.[21,99]

In 1973, EPA announced regulations requiring a gradual reduction in the lead content of each refinery's total gasoline pool. At that time, the average gallon of gasoline had 2.2 grams of lead. The lead phase-down would start January 1, 1975, with a reduction to 1.7 grams and continue to 1979 with a reduction to 0.5 grams per gallon.[100] Ethyl Corporation filed suit to keep lead in gasoline, and in late 1974, a panel of the U.S. Court of Appeals for the District of Columbia Circuit set aside EPA's lead regulations as "arbitrary and capricious," ruling in favor of Ethyl and DuPont. But the decision was reversed in 1976, when the full Court of Appeals cleared the way for a continued lead phase-down. The court held that the Clean Air Act Section 212 was meant to be precautionary and did not require proof of actual harm before regulation was appropriate.[101]

Meanwhile, automakers equipped new cars with pollution-reducing catalytic converters designed to run only on unleaded fuel starting in 1975 and 1976, and new unleaded gasoline pumps began appearing at filling stations nationwide. At that time, the average blood lead level in children under age 6 was 16.5 µg/dL. By 1985, 40% of all gasoline sold was still leaded, but in July of that year, the refinery pool standard of 1.1 grams per gallon dropped to 0.5, then dropped further to 0.1 grams per gallon on January 1, 1986. Over all, the 1986 standard represented a drop of more than 98% in the lead content of U.S. gasoline from 1970 to 1986.

With the phase-out of leaded gasoline, the average blood lead level had dropped by 1996 to 3.6 µg/dL, and it continues to decline. Similar declines in blood lead levels corresponding to leaded gasoline phase-outs have been observed in many other nations.[102] Lingering public health threats to children from leaded gasoline are still associated with residual lead in urban soils.[103]

Lead content in gasoline peaked in 1973 at an average of 2.2 grams per gallon, which amounted to about 200,000 tons of lead used per year in the United States. In 1995 leaded fuel accounted for only 0.6% of total gasoline sales and less than 2,000 tons of lead per year. Effective January 1, 1996, the Clean Air Act banned the sale of the small amount of leaded fuel that was still available in some parts of the country for use in on-road vehicles. (Fuel containing lead was still permitted for some off-road uses, including aircraft, racing cars, farm equipment, and marine engines).[104]

In 1996, the International Bank for Reconstruction and Development (the World Bank) recommended global phase-out of leaded gasoline. The bank said the estimated benefits from savings in health care were worth more than ten times the costs of switching to TEL alternatives. These alternatives "are commercially available and technically well understood." These included isomerization and alkylation processes, as well as the use of oxygenates (alcohols) that help fuels burn cleaner and more completely, and "could be part of environmentally responsible lead phase-out strategies," the bank said.[105] Following a phase-down period, in 2000 the European Economic Community also banned most leaded gasoline.[106] Laws prohibiting leaded gasoline have been adopted worldwide in recent years.[107]

Leaded gasoline is still being phased out in most developing nations. The "Declaration of Dakar," approved June 28, 2001, involved the World Bank and 25 sub-Saharan African nations in a plan to clean up the air quality in African cities. The most important part of the program was a phase-out of leaded gasoline. Cheering from the sidelines, the company that was once Standard Oil saw it as "an opportunity to cooperatively take an important step toward improving the quality of life for the citizens of African countries."[108] Still, some nations such as Iraq and Jordan continue to use leaded gasoline.[109,110]

CONCLUSION

Lead poisoning is one of the oldest known forms of occupational and environmental disease. When scientists objected to the introduction of leaded gasoline in the 1920s, they felt they had the obvious benefit of historical understanding. But deliberate miscalculations of the volume of leaded gasoline residues, political opposition, and positivistic attitudes about science meant that public health advocates could not block industry's use of lead in gasoline in the 1920s.

Ethyl and the industries presented a very clear challenge to public health. There claimed to be no alternatives to leaded gasoline, which was a "gift of God" necessary to the functioning of modern civilization. However, as we have seen, alternatives were already in place and being used within the oil industry in the United States and Europe. Additionally, GM had been in the forefront of research into alternatives, and GM researchers were on record as calling for more use of the alternatives, although they were also on the record as saying that they didn't exist. Finally, the original special motive for developing leaded gasoline was the auto industry's desire to be independent of the oil industry in case of widespread petroleum depletion. Leaded gasoline technology was originally nothing more than a temporary expedient to raise octane and allow engine compression ratios to rise as well. This would create a bridge to what GM researchers called the "fuel of the future," ethyl alcohol.

However, when the expedient proved highly profitable in its own right, GM, DuPont, and Standard Oil decided to improve the occupational health situation in the refineries and overlook the serious public health problems posed by leaded gasoline. Governments were pressured, contradictory reports were misplaced, and scientific research was channeled into amenable institutions. The apparatus and authority of science became suborned as an instrument of profit for the lead mining, oil refining, and automotive industries.

By the 1960s, a hegemonic system of occupational and public health science had been created around the lead issue. It is significant that only scientists from outside the usual disciplinary constraints challenged industry at the time. Two principal examples were geochemist Clair Patterson, who exposed flaws in the scientific methods of the lead industries, and Herbert Needleman, a psychiatrist whose epidemiologic studies correlated higher lead levels with worse school performance and lower IQ levels in children.

We are often led to expect that technologic choices are made by a scientific method that reveals the most important properties of a technology. As historian T. P. Hughes said, good scientists systematically work through all available options when developing a new technology.[10] But, in fact, there are very few knowledgeable representatives of the public interest looking over the shoulders of industry when such decisions are made, and with 20–20 historical hindsight, it is clear that the decisions are often not being made with the public or even the best possible technology in mind. Lead poisoning was among the most obvious and historically well known occupational diseases, and even though, as Alice Hamilton noted, alternatives were perfectly obvious, the industry opted instead for profitable poison.

References

1. Personal communication with the family of J. G. Leslie, May 2005.
2. U.S. Census, 1920, Enumeration District 89, Elizabeth NJ.
3. Personal communication with David Shoenbrod, Natural Resources Defense Council, June 2005.
4. *Ethyl Corp, v. Environmental Protection Agency*, U.S. Circuit Court of Appeals for the District of Columbia Circuit, 176 U.S. App. D.C. 373; 541 F.2d 1; 1976 U.S. App. LEXIS 12309; 8 ERC (BNA) 1785; 6 ELR 20267, decided March 19, 1976.
5. Chicago issues ban on leaded gasoline. New York Times. 1984: Sept 8, Sect. A:42.
6. Bar ethyl gasoline as 5th victim dies. New York Times. 1924; Oct 31, Sect. A:22.
7. Gavaghan H. Lead, unsafe at any level. Bulletin HO. 2002; 80 (1).
8. Lovei M. World Bank Support for the Global Phaseout of Lead from Gasoline. Washington, DC: The World Bank, May 1999.
9. Allen OE. Kettering. American Heritage of Invention and Technology magazine, Fall 1996.
10. Hughes TP. Inventors: the problems they choose, the ideas they have, and the inventions they make. In: Patrick Kelly P, Kransberg M (eds). Technological Innovation: A Critical Review of Current Knowledge. San Francisco, CA: San Francisco Press, 1978: 177.
11. Robert JC. Ethyl: A History of the Corporation and the People Who Made It. Charlottesville, VA: University Press of Virginia, 1983.
12. Boyd TA. Professional Amateur. New York: E. P. Dutton, 1957.
13. Young R. Boss Ket. New York: Longmans, Green & Co., 1961,
14. Rosner D, Markowitz G (eds). Dying for Work: Workers' Safety and Health in 20th Century America. Bloomington, IN: Indiana University Press, 1989.
15. Rosner D, Markowitz G. Deceit and Denial. Berkeley, CA: University of California Press, 2003.
16. Midgley T to Kettering, March 2, 1923, Factory Correspondence, Kettering Collection, unprocessed Midgley material, GMI.
17. Wescott NP. Origins and Early History of the Tetraethyl Lead Business, June 9, 1936, Du Pont Corp. Report No. D-1013, Longwood MS Group 10, Series A, 418-426, G. M. Anti-Trust Suit, Hagley Museum & Library, Wilmington, DE, p. 22.
18. Another man dies from insanity gas. New York Times. 1924; Oct 28, Sect.A:1.
19. No peril to public seen in ethyl gas. New York Times. 1924; Nov 1, Sect. A:1.
20. Bent S. Tetraethyl lead fatal to makers. New York Times. 1925; Jun 22, Sect. A:3.
21. Albemarle takes ethyl corp title. New York Times. 1962; Dec 1, Sect. A:1.
22. Hughs J. Ecology in Ancient Civilizations. Albequerque, NM: University of New Mexico Press, 1975: 5.
23. Nriagu J. Lead and Lead Poisoning in Antiquity. New York: Wiley Interscience, 1983: 12.
24. Sugar of lead. Sci Am. 1857; Aug. 29. 403.
25. Ramazzini B. A Treatise on the Diseases of Tradesmen, c. 1700, cited in Thompson LR. Knowledge of Industrial Hygiene in the Early Days of History, unpublished, National Institutes of Health, RG 443 Box 195, National Archives, Washington, DC.
26. McCord CP. Lead and Lead Poisoning in Early America: Benjamin Franklin and Lead Poisoning. Ind Med Surg. 19;22: 393-9.
27. Smith M. Lead in history. In: Lansdown R, Yule W (eds). Lead Toxicity: History and Environmental Impact. Baltimore, MD: Johns Hopkins University Press, 1986: 21.
28. Dickens C. The Uncommercial Traveler, cited in Nriagu.[23]
29. Sicherman B. Alice Hamilton: A Life in Letters. Cambridge, MA: Harvard University Press, 1984.
30. Boyd TA. Motor fuel from vegetation. J Industrial and Chemical Engineering, 1921;13:836-41.
31. Kovarik W. Ethyl: the 1920s environmental conflict over leaded gasoline and alternative fuels. In: Proceedings of the American Society of Environmental History, Providence, RI, March 25, 2003.
32. Midgley T. The chemical control of gaseous detonation with particular, reference to the internal combustion engine. Industrial and Engineering Chemistry. 1922; Oct.
33. Clark WM to AM Stimson, Oct 11, 1922, AM Stimson to RN Dyer, Oct 13, 1922, Dyer to Surgeon General, Oct 18, 1922, N Roberts to Surgeon General, Nov 13, 1922, HS Cumming to P DuPont Dec 20, 1922, and T Midgley to HS Cumming, Dec 30, 1922; U.S. Public Health Service Record Group 90, National Archives, Washington, DC.
34. Boyd TA. The Early History of Ethyl Gasoline. 193.
35. New $5,000,000 gasoline concern. New York Times. 1924; Aug 22, Sect. A:22.
36. Testimony of WF Harrington, *United States vs. DuPont de Nemours Inc. et al.*, 1953: 3814.
37. Odd gas kills one, makes four insane. New York Times. 1924; Oct. 27, Sect.A:1.
38. "The terrible loony gas. . ." Cartoon, New York Journal, Oct 29, 1924.
39. Company denies negligence led to gas deaths. New York Sun, 1924; Oct. 27, A1.