Birth of the Kettering Doctrine: Fordism, Sloanism and the Discovery of Tetraethyl Lead

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In 1921, General Motors discovered that tetraethyl lead, when added to gasoline, would solve the problem of engine knock. This was a discovery that promised enormous commercial value. It cleared the way for automakers to design engines that would be far more efficient and powerful, giving its inventors a tremendous strategic advantage. Perhaps more importantly, tetraethyl lead came to serve as tangible support for a set of ideas about how industrial organizations relate to society.

This article reviews the early history of tetraethyl lead, the reasons for its development, the evolving set of automotive virtues to which its benefits would be applied, and the doctrines that arose from its development. When the automobile was introduced 100 years ago, it was clear that it represented modernity and progress, but no one at the time could foretell what societal function it would serve. Its future role was a blank slate. The story of tetraethyl lead starts there.

Introduction of the Automobile

Individuals for the first time gained the ability to travel by mechanical power under their own direction with the bicycle. Around 1880, bicycle clubs were organized to tour the countryside, and races were held. Some inventors began to imagine what possibilities of personal mobility lay ahead if touring could be motorized. For such a thing to happen three essential elements had to be developed: (1) An engine would have to have enough power to propel the combined weight of engine, vehicle and passengers. The engines then in existence were too heavy and bulky to be of practical use. (2) Likewise, its power source would have to have a high energy density relative to its weight; petroleum fuels and electric batteries were possible sources. (3) Smooth, durable roads would need to be built.

In Europe, Carl Benz began the first commercial production of motor vehicles in 1886 using an engine of internal combustion design. Paris became the center of production because, of the three automotive essentials, France at that time had both viable motor technologies and a road system that was unsurpassed in the Western world. No one yet had mastered the fuel.

The automotive age was born on June 11, 1895 when twenty-three autos began a race from Versailles to Bordeaux and back to Paris, a distance of 727 miles. The spectacle fired public imagination worldwide: to think, someone had discovered how to build carriages that propelled themselves — "auto-mobiles" —

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without horses to pull them. Prior to the race, few people had ever seen such vehicles, and less than ten percent of the public even knew they existed.

The news reached America quickly. Not to be outdone, Herman H. Kohlsaat, Editor of the Chicago *Times-Herald*, announced a race from Chicago to Waukegan and back, a distance of 92 miles. Because of the $5000 in prizes offered, the contest was headlined in newspapers all over the country. To permit inventors to finish their autos in time, the race was postponed as late as weather would allow. By the time it was run, on Thanksgiving Day, November 28, 1895, conditions were snowy and bleak. Of the 83 contestants who had initially signed up, only six appeared at the starting line and only two finished — both of them gasoline-fueled internal combustion vehicles. Nevertheless, when the prizes were handed out, the winner, entered by the Duryea brothers of Springfield, Massachusetts, received a cash prize of $2,000, but the Gold Medal for best automobile went to the Electrobat, an electric car that did not even reach the finish line.

In introducing the car, the 1895 Chicago Race also introduced the use of the car for racing. Soon similar races began to be held all across the country as popular diversions. Thus, the 1895 Chicago Race established racing as a test of automotive virtue, providing the medium for making innovations, the incentive to advance them, and the way for automakers to get publicity for them.

Steam Versus Electric Versus Internal Combustion

These events demonstrated the potential of the automobile but not the form it would take. What would the automobile be like? With anything possible, a wide variety of vehicle types began to appear. The 1895 Chicago Race introduced speed, but it was the endurance drive that demonstrated the viability of the automobile. In August 1897, Alexander Winton, a Cleveland bicycle manufacturer, drove a car he had built from Cleveland to New York City in only 78 hours. Because of the publicity he gained, Winton repeated his drive in 1899, cutting his time to less than 48 hours. In his second drive Winton took a newspaper reporter who filed articles along the way; over a million people turned out to see the car when he reached New York. It was a turning point: it was now clear that the car could do things a horse or a bicycle could never do.

Steamers and electrics took an early lead in auto sales and held it for several years. And yet, as early as 1904 the internal combustion engine emerged as the preferred vehicle type. One might suppose that the internal combustion vehicle prevailed because of its technical superiority. But in fact, it overtook steamers and electrics even before its major technical advances had occurred. The most successful internal combustion car, the curved-dash Oldsmobile, introduced in 1901 and by 1904 the largest selling car of any type, was inexpensive, reliable and easy to repair but did not introduce any major technological advancements. If not technical superiority, why did the internal combustion vehicle eclipse its rivals?

The answer is to be found in its distinctive virtues, that is, those desired amenities motorists perceived they would obtain with use of the car. During the first decade of the automotive age, each of the three auto types represented a different collection of virtues from the two others, and each was built for distinct uses in keeping with its character. Because electric vehicles operated without burning fuel, they were clean, quiet, reliable and easy to maintain. They were easy to drive and started at the touch of a button, unlike internal combustion cars, which required the driver to turn over the engine with a hand crank to start. Internal combustion cars, by contrast, had superior performance characteristics, which made them capable of long range with quick refueling. Moreover, they used petroleum fuels that were inexpensive and available everywhere. Steamers fell in between the two other types, sharing characteristics with both. They could run at full power at low speed and therefore, like electrics, they did not need a transmission, clutch or gearshift; they had fewer moving parts overall, which made them simple to build at low cost, and they were quieter to operate than internal combustion vehicles. At the same time, like internal combustion vehicles, they had racing victories to their credit and used readily-available kerosene or gasoline for fuel.

Of 15 virtues ascribed to vehicles in the press, advertizing and trade literature of the day,[1] electrics and internal combustion vehicles had only two virtues in common — neither was economical to buy, and ownership of a car of any type conveyed status and distinction upon its owner. In all other aspects they differed, not just in degree but categorically. Steam constituted a different third alternative. Indeed, it would be mistaken to think of the automobile as a single commodity then. All were automobiles, certainly, but only in the way that wheat, corn and barley are all grains.

As no single auto type offered all of the automotive virtues, deciding the technology for the automotive age was primarily a matter of motorists' selecting the auto type that represented the set of virtues they most prized. Since early auto buyers chose the internal combustion auto, its particular virtues — speed and power, range and infrastructure — must have been the ones that counted. But why these virtues and not their alternatives? One reason is that these virtues enabled a motorist to fulfill the most basic of requirements: to venture forth and return to the same place. At that time, city folk were the principal car buyers, and a car's use was principally recreational. Cars had replaced bicycles as the means for affluent urbanites who could afford them to get out to enjoy the countryside. Had motorists intended to drive only in urban areas, electrics might have served just as well, if not better. But urban motorists could not take a country drive in an electric without the risk of becoming stranded; likewise, steamers required a water infrastructure that did not exist. Speed was another very important consumer selling point. The car came to the public's attention as a racing vehicle and was marketed as a new form of sport, thus it was implicit that speed was a virtue that cars should have. The issue was settled by 1904-5. Internal combustion cars alone offered a combination of speed and power, range and infrastructure that gave motorists the ability to achieve the automotive purposes they desired.

With the passage of time motorists would not weigh speed and power, range and infrastructure equally. After internal combustion began to emerge as the victor, all the investments in auto infrastructure went into serving it, and as its infrastructure grew the importance of infrastructure receded as a consumer choice criterion. Likewise, range was critical initially, but it was inversely paired with the

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[1] These are: clean (free of smoke and odor); quiet; reliable; free of vibration; safe (free of heat; low cost of insurance); easy to drive and control (ease of handling); instant starting; elegance/style/workmanship; simple construction/few repairs; economical to run; economical to buy; status of ownership; speed/power; infrastructure; distance/range.

fuel infrastructure. Of the automotive virtues, only speed and power represented values inherent to the engine technology, and they rose in importance as automotive virtues.

Fordism: A New Set of Automotive Virtues

Having achieved market leadership, the internal combustion car became the single focus of development efforts. Automotive virtues that had once belonged solely to electric vehicle types began to be incorporated into internal combustion vehicles, and an internal combustion car that incorporated more of the 15 automotive virtues began to take shape. Technological development advanced in the direction of greater speed and power. Few automakers recognized the message in the success of the curved-dash Oldsmobile: that building an auto at a price middle class consumers could afford would bring a flood of buyers.

Others had missed that point, but Henry Ford got it. On October 1, 1908, Ford introduced the Model T as a popularly priced, no-frills car. Unlike other automakers, Ford introduced key innovations in the lowest price category. As a result, the Model T offered a level of quality and reliability that had not previously been available in any low-priced car. It was a car that almost anyone could afford, that ordinary men could keep in repair, and that motorists could drive anywhere. While the Model T had excellent power for its class, it by no means emphasized speed. To Ford speed implied leisure, and in his farm-boy ethic leisure was a wasteful indulgence. With affordable and reliable automotive transportation now available to the middle class, the automotive virtue of utility ascended, and the virtues of speed and power were put aside.

In 1910, Ford turned to redesigning the process for manufacturing the Model T. Advanced manufacturing up to that time involved standardization of parts and division of labor, and by this means multiple copies could be produced from a single design. But assembly of a car remained largely a matter of craftsmanship. The Model T changed all this: Because it was cheap enough for the middle class to afford, consumer demand for it was large enough to support an unprecedented volume of production; in turn, the economies of scale achieved by producing in such volume enabled Ford to lower his price even further, bringing car ownership within reach of an even larger number of consumers. This condition set the stage for Ford's great leap forward: in 1913 Ford introduced the moving assembly line, which allowed the price of the Model T to plummet and caused sales to skyrocket. Its individual elements — production efficiencies, low unit mark-up, high consumer demand and massive production volume — were coordinated to work together. Ford's role was so identified with this new process that until Ford himself coined the term "mass production" in 1926 the process was popularly referred to as "Fordism."[2] Fordism was the combination of price and quality that put America on wheels. It was quickly imitated by others automakers.

As the Model T's price fell and its sales increased, more workers were employed to produce it and the middle class grew larger and richer; in turn, production volume increased, which made possible both additional economies of

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[2] The term "mass production" originated in an article published by Henry Ford in *Encyclopedia Britannica* in 1926.

scale and additional employment. Ford had triggered a wealth-creating upward spiral that rapidly changed the American standard of living, limited only by the size and buying power of the middle class. Thus, under Fordism mass production depended upon mass consumption. In December 1913, Ford unilaterally raised its workers' salaries to five dollars per day, roughly twice the prevailing wage. At the time, no one — especially Henry Ford himself — understood the full significance of the five-dollar day. But once the adulation started coming in Ford was willing to take full credit. The enormous public acclaim made him a mythical figure overnight.

While the 1910s were dominated by the Model T, large and powerful cars also continued to be built that were out of reach of the middle class. The technology that would permit speed and power to become popularly priced would be developed later by General Motors ("GM"), formed in 1908 by William C. Durant.

In the first 15 years of the automotive age, all the innovations made on the car advanced its engine and physical structure — that is, the metallurgy of the vehicle. Other essential systems, including the electrical system and the engine-fuel combination, remained far from perfected. Both of these developments were to be the product of the brilliance of one man — Charles F. Kettering.

Conservation: Charles Kettering and the Antiknock Research

At the turn of the century, Dayton, Ohio was a hotbed of invention. In their Dayton bicycle shop Wilbur and Orville Wright were experimenting with powered flight. Also in Dayton, the National Cash Register Company ("NCR") was developing the machines that would revolutionize business practice. In July 1904, NCR hired Charles F. Kettering as an engineer. Kettering, 27 years old at the time, was brought on by assistant general manager Edward A. Deeds to electrify the cash register. Experts who had previously examined that possibility had concluded that a practical electric cash register was against the laws of physics because its motor would have to be as large as the cash register itself. Kettering saw, as the experts had not, that the solution would not require continuous force but only a high torque, short burst of power. Kettering did not stop to puzzle over it — he just figured out how to do it, designing what became the world's first electric cash register.

In the summer of 1908, Deeds and Kettering discussed getting into the growing automobile industry. Deeds recognized that it was beyond their means to start a new car company; the next best thing would be to invent something to put onto cars. Kettering had already given this some thought. He had heard that Cadillac was very dissatisfied with its ignition systems, and had sketched out the design of a new, improved system. He and began to meet with Deeds and a crew from NCR in Deeds' barn during off hours to perfect his design. After a year of work the "Barn Gang" perfected a new, more reliable ignition system and sold it to Cadillac for installation on 1910 models. To run their new business they incorporated a new company, the Dayton Engineering Laboratories Company — "Delco."

In July 1910, Kettering began work on his second auto innovation, the first practical auto self-starter. Others, including Thomas Edison, had tried to design a self-starter but had failed. Kettering was undaunted. Like taking the crank off the cash register, the solution was to devise a compact motor that would deliver a short burst of power. Within six months Kettering perfected a redesigned electrical system that integrated a motor/generator unit, a storage battery, and electric lighting. Cadillac introduced the new system in August 1911 on its 1912 model. It was worth a $10 million order to Delco, and by 1914 Delco occupied a 5-story building to house its 1200 employees. In the larger scheme, the starter incited an automotive revolution: Dispensing with the hand crank made it practical for any woman to drive an internal combustion car. The self-starter also made it possible to offer larger engines with eight or more cylinders and higher compression ratios that many individuals would have found difficult to crank by hand.

In June 1910, Kettering bought a copy of a book entitled *The Internal Combustion Engine*.[10] In it, Kettering found a 100-page treatment of thermodynamics with an extensive discussion of the relationship of compression ratio to efficiency. The pursuit of thermodynamic efficiency in internal combustion engines was to become Kettering's lifelong obsession. Kettering reasoned that the long-term survival of the auto industry depended upon improving efficiency: unless a solution to the recurring oil shortages could be found, the car's fuel might soon be depleted.

Experience told Kettering that the solution to oil shortages lay in solving the problem of knock. Knock is a phenomenon of engine performance that sounds like two metal parts striking together; this pinging noise gives knock gets its name. Knock is mechanically inefficient and can damage the engine. No one had shown what caused knock, but it was recognized that it was related to higher engine "compression ratios" — that is, the ratio of the volume in the combustion cylinder at the bottom of the piston stroke (its most expanded volume) to the volume in the cylinder at the top of the stroke (its most compressed volume). Because the occurrence of knock increased as the compression ratio increased, knock formed a barrier, an upper limit on an engine's compression ratio at the threshold at which knock would begin, about 4 to 1 (4:1). But in doing this, automakers sacrificed the thermodynamic efficiency that would be possible with a higher compression ratio. Most experts had resigned themselves to the inevitability of knock; Kettering decided to find the solution.

On October 1, 1916, a Saturday afternoon, Kettering called in his young associate Thomas J. Midgley, Jr. for a talk. Kettering had set up a new company, the Dayton Research Laboratories Company, to conduct research he had found difficult to accomplish at Delco. Kettering thought that such a laboratory could do for the automotive industry what Edison had done for electronics. Midgley, a mechanical engineer, was hired as the Laboratory's first employee. His first assignment would be to find the cause of knock.

In the 1910s, conventional wisdom held that knock was caused by "pre-ignition," that is, ignition of the fuel in the combustion chamber before the spark plug fired. On November 17, 1916, in his very first experiment measuring the knock sequence, Midgley found that the sharp pressure oscillations associated with knock did not occur before the spark plug fired, but after. This was a surprise: it indicated that all the theories were mistaken.

They decided to experiment to see if knock was caused by the fuel. Midgley suggested that a better vaporization of the fuel would create a more homogenous mixture that would burn more smoothly, and that dyeing the fuel red would cause it to absorb heat and vaporize more completely. Midgley apparently confirmed this theory on the very first try: on December 2, 1916, Midgley discovered that adding iodine to kerosene caused a notable decrease in knock. However, after tests with other red dyes failed and tests with a colorless iodine compound succeeded, Kettering and Midgley realized that iodine's antiknock property had nothing to with its color; it resulted from some other chemical property of iodine they had not identified.

Recognizing that extensive research might be required, Kettering set Midgley up in a lab to investigate the cause of knock. His work attracted the attention of the U.S. War Department and the Interior Department's Bureau of Mines because of their interest in increasing the compression ratio of warplane engines. Engine efficiency is even more critical to aviation than it is to automobiles, as the key to aircraft lift and flight distance is maximizing the power-to-weight ratio. High-compression engines could dramatically improve the speed and power of aircraft if the knock problem were solved. Midgley and newly hired Thomas Boyd developed a fuel blend composed of 70 percent cyclohexane (C_6H_{12}) and 30 percent benzene (C_6H_6) that enabled them to boost the compression ratio of aircraft engines from 5.5:1 to 8:1. Shortly after the end of the War, on January 30, 1919, Boyd discovered that aniline (C_6H_7N) had much better antiknock qualities than iodine. Midgley obtained a patent for aniline and began work to commercialize it.

At that time conservation had a very receptive audience. World War I had made the public sensitive to potential energy shortages, and experts began to extrapolate this problem to general conditions. In the spring of 1919, Kettering presented their findings in a paper called "More Efficient Utilization of Fuel." Underscoring the need was the growth of the automobile population: between 1912 and 1920 domestic crude oil production had doubled, while the number of autos increased nine-fold. Kettering's speech seemed prescient, as the U.S. was hit once again with a severe petroleum shortage in the late spring of 1920.

Sloanism: Under GM's Agenda a Return to Speed and Power

In 1919, Kettering's antiknock research came under control of GM, and its mission changed. Its new agenda bore the stamp of Alfred P. Sloan, Jr., the organizational genius of GM.

While Ford had made himself a mythical figure, GM had stumbled badly in its first few years. As Billy Durant acquired more companies, GM had become financially overextended. Durant was ousted by GM's bankers in 1910.

This assured that it was Ford, not GM, that popularized the automobile. During the 1910s, the public had put aside its earlier preoccupation with speed and power and had come to think of the automobile as a more practical form of transportation along the lines of Ford's Model T. By 1916 Ford had achieved a comfortable market dominance. The Model T was not sleek, fast or powerful, but it provided unprecedented personal mobility at a price middle class families could afford. The car had become an essential of life rather than strictly a luxury or recreational item. Ford's single-minded pursuit of cost reduction had worked, but in the 1920s he was to become a victim of his own dazzling success: while others had continued to advance the technology, Ford had blocked his engineers (and even Edsel) from making changes.

Meanwhile, GM's bankers had pushed Durant aside but not out of the game. In 1911, Durant had founded a new company, the Chevrolet Motor Company, named for a famous French/Swiss race car driver, and set out to build "a car worthy of the name, a car for power, speed, stability, appearance and price." However, Durant soon recognized the 1910s as an era of utility and economy, and he restyled the Chevrolet as an economy car. The Model T was unassailable on price, but it could be challenged by offering the value-adding amenities that it lacked — a self-starter, electric lights, detachable wheels, etc. Under this strategy Chevrolet became so successful that by June 1916 Durant was able to accumulate enough GM shares to regained a controlling interest in GM and retake the presidency. GM later absorbed Chevrolet. Once back in control, Durant again tried to build his empire by making acquisitions. In a series of purchases GM acquired all of Kettering's companies, including the Research Laboratory, bringing the laboratory within the GM family and giving Kettering a sizable amount of GM stock. Kettering was made GM vice-president for Research.

But Durant's purchases again were excessive, and his second presidency came to the same fate as his first. Pierre S. du Pont, president of the du Pont Company, who had begun buying GM stock in 1914 and in 1915 was elected GM's chairman, replaced Durant as GM president on December 1, 1920. At 12 percent market share in 1921, GM remained a small contender, but under its new leadership GM was now ready to take on Ford and had no attachment to the status quo.

As part of the GM family, Kettering's laboratory participated in the evolution of a new competitive strategy that has come to be known as "Sloanism," after Alfred P. Sloan, who became president of GM in 1923. Sloanism consists of two principal elements. First, Sloan recognized that Fordism would reach a dead end when the market became saturated, that is, when all motorists who could afford cars had bought them. Sloan realized that unless automakers gave a motorist a reason to buy a new car even when he already had one, automakers would have no one left to sell to. Sloan's solution was the annual model year changeover. Of course, selling a new car to a motorist who already had one required convincing him that the newer model contained some improvement over his current car.

Kettering had an economic rationale that gave this a public purpose. To Kettering, planned obsolescence would not only stimulate auto sales, it would advance the technology, which Kettering equated with human progress. Indeed, Kettering believed that making products obsolete was necessary for rapid progress because overly-satisfied customers would decrease auto demand and stall the economy. He later wrote, "Self-satisfaction is one of the world's worst diseases." As the new head of GM research, Kettering was in the position to supply the annual innovations that would create that consumer dissatisfaction. Kettering understood that solving the knock problem would create a revolution in auto technology that would sustain auto demand.

Second, Sloan called for GM to build "a car for every purse and purpose," so that there would be no market in which GM did not offer a product. Sloanism gave the consumer choices and allowed him to move up in class of luxury without having to leave the GM product family. GM invented the concept; it was the only automaker to offer a full line. But producing a full line was more easily said than done. It required a balance GM had not yet achieved: in early 1921 GM did not have a model that competed effectively with the Model T in the low-price, high volume category.

Among the research projects Kettering brought with him to GM was the concept of a new air-cooled engine, which Pierre du Pont liked to call the "copper-cooled" engine. In the spring of 1921, GM's Executive Committee decided that the way to compete with Ford was to commercialize Kettering's engine and put it in the Chevrolet, which would lower costs and allow Chevrolet to compete on a price basis. But in the summer of 1923 the copper-cooled engine was canceled for two reasons: First, those that were built suffered from technical flaws, caused in part by poor coordination between Kettering's laboratory and GM's motor divisions. Second, GM came to recognize that its focus on the economy market was a mistake. By the early 1920s, society was approaching the point where car ownership by itself no longer conferred status; once most middle class families owned a car, social distinction would come only with having a car that was better than one's neighbors'. In addition, Fordism had standardized consumption, but in doing so it had also standardized the consumer, and auto buyers tired of the lack of variety. Now that they had equity in their cars, many motorists wanted to trade up to a higher class of luxury. In a sense, it was a return to the era that existed prior to the appearance of the Model T. What was different now was that its virtues were to be made available to the middle class, the "mass-class" market, as Sloan called it [8].

Abandoning its considerable investment in the copper-cooled engine, GM refocused on supplying the middle class market, where the future growth would be. GM saw that Ford was pursuing a declining market. In this context, the antiknock research gained a value different from Kettering's obsession with efficiency. Kettering had initiated the antiknock research to find a way to conserve fuel, and it was true that increasing the compression ratios of engines could be used to achieve higher mileage per gallon and save fuel. That would involve replacing larger engines with smaller, more efficient ones of equal horsepower. But that's not the only way the new efficiency of high-compression engines could be spent. The efficiency gains could also be used to build more powerful engines, making speed and power available in popularly priced cars for the first time. This would enable GM to design larger and racier cars and sell them at moderate prices. As Sloan recognized, it was for cars such as these that an unfulfilled consumer demand existed.

The copper-cooled engine had taught Kettering a very important lesson that was to be applied to the antiknock research. Both projects had originated at Delco in the Fordist period. The copper-cooled engine represented utility and economy, but in pushing these virtues Kettering had cost GM millions and nearly destroyed his credibility in his new job. From this experience Kettering recognized that the Fordist era of utility and economy had passed. The lesson was that you can't sell many cars on conservation.

By 1923, the year Alfred P. Sloan succeeded Pierre du Pont as GM president, it was clear that Kettering's original purpose for the antiknock research had given way to GM's desire to improve auto performance without regard for its effect on fuel economy. Instead of economy, the increase in efficiency yielded by the higher compression ratio would be spent on speed and power. Kettering's antiknock research had become part of GM's strategy to make available to the middle class the luxuries that had been accessible only by the rich, and in doing so to knock Ford out of his market dominance. Kettering did not give up on efficiency and conservation as his own ideals, but ever after he knew better than to try to push a product that would not sell. In later years, even as Kettering's advocacy of conservation became more and more public, it represented GM's true motive less and less.

Midgley's team proceeded with the antiknock research by trial and error, but by early 1921 all its trials were errors. The Lab had spent considerable effort over two years to commercialize aniline, only to find that it was unacceptable: (1) it corroded engine metals, and it oxidized to produce sticky and troublesome deposits; (2) it would also be costly and was poisonous; and (3) its exhaust had a terrible odor. This situation brought the antiknock research to its point of lowest morale. But Kettering persisted.

On a train from New York, Kettering noticed a newspaper article that reported discovery of a new substance with potent solvent properties, selenium oxychloride (Cl_2OSe). Kettering suggested that Midgley test its antiknock potential. On April 6, 1921, Midgley tested it and found that its antiknock quality was about five times more effective than aniline. However, the exhaust from using it had a terrible smell. Two days later, they tested a similar substance, diethyl telluride ($(C_2H_5)_2Te$). It was less corrosive and was four times more effective than selenium. But its smell was simply unbearable — they called it a "satanic garlic smell." Most fatally, neither of these elements was available in quantities sufficient for commercialization. While neither had proven acceptable, Kettering's team was getting closer and they knew it.

To give the research a little direction, Midgley consulted Dr. Robert E. Wilson at MIT. Wilson suggested that Midgley use Langmuir's periodic table, which was organized according to chemical valence. By charting the discoveries they had already made, Midgley observed a pattern that pointed to lead. To make elemental lead soluble in gasoline, they formulated it as tetraethyl lead ($Pb(C_2H_5)_4$). On December 9, 1921, they first tested tetraethyl lead with a sense of great anticipation. The reduction in knock was even more stunning than they anticipated: its first test, at a concentration of 1 percent in the fuel, was entirely free of knock, so Boyd added more fuel to dilute it; when knock did not appear, he diluted it again, and continued to dilute it until the first knock appeared, at 1/40th of 1 percent. Midgley told Wilson about their discovery at an SAE meeting held in New York on January 11-12, 1922: Midgley, in a state of great excitement and secrecy, pulled out a test tube containing tetraethyl lead and showed it to Wilson. *This*, Midgley told Wilson, is "really the answer to the whole problem."

Kettering and Midgley soon recognized that the use of lead additive would have two drawbacks that would have to be overcome: (1) The combustion of tetraethyl lead in the engine produces lead oxide that builds up as a deposit of solid material and causes damage to spark plugs and exhaust valves. To address the deposit problem the laboratory embarked on a new research program to get the lead to leave the engine in the exhaust. They found that lead oxide could be prevented by adding organic halides, specifically soluble compounds of chlorine and/or bromine, to the gasoline along with the tetraethyl lead. During combustion, these "scavengers" would combine chemically with the lead and carry it out of the engine. In 1925, they settled on ethylene dibromide ($C_2H_4Br_2$) as the scavenger. (2) The use of lead in gasoline has a more dangerous drawback, its hazard to human health. Unlike the deposit problem, which GM could and would resolve privately, the human health hazard problem was a matter that ultimately had to be decided by public authorities.

Kettering decided to move quickly to commercialize gasoline lead additive. In Kettering's view, it was better to bring a product to market quickly than wait for complete resolution of its associated problems. To give gasoline containing tetraethyl lead a name with character, Kettering decided to call it "Ethyl gasoline." To give Ethyl gasoline a distinctive appearance, Boyd suggested that it should be dyed; recalling Midgley's original discovery using iodine, they decided to dye it red. On February 1, 1923, at Sixth and Main streets in Dayton, Ohio, GM's Ethyl gasoline was first offered for sale. This was a small beginning, but its implications were already being recognized. On March 9, 1923, Midgley was awarded the Nichols Medal by the American Chemical Society for his discovery of tetraethyl lead.

Meanwhile, to avoid having to pay licensing fees to others, Standard Oil of New Jersey developed a new, more efficient method for producing tetraethyl lead. On August 18, 1924, GM and Standard Oil pooled their patents to create the Ethyl Gasoline Corporation. Ethyl was to market gasoline lead additive produced by Standard Oil and du Pont. GM and Standard Oil would each hold half of the equity in the new company. The board appointed Kettering as its president; Midgley, as second vice-president and general manager, was assigned responsibility for actually managing the enterprise. Within a few years Ethyl developed the "octane" scale as a way to measure the antiknock property of a fuel. Octane remains the most important consumer measure of gasoline quality.

With the discovery of tetraethyl lead the problem of knock was solved. This had far-reaching effects, both as to its technological merits and its impact on industrial society generally

Lead Additive and Automotive Virtues

Technology Innovation and Competitive Strategy

At the beginning of the automotive age the technologies that were developed for the car were those that could be put to use in service of the most favored transportation virtues. Technology defined the car's capabilities, but did not dictate which of those capabilities were selected by motorists. To the contrary, motorists' technology choices revealed what those favored virtues were.

The automotive virtues of speed and power were evident from the dawn of the automotive age, but their use changed over time. The car was introduced through racing in 1895 and in its first decade its uses were principally recreational. During its second decade the car became predominantly utilitarian, and by 1915 the shift to functionality was complete. During the third decade, from 1915 to 1925, speed and power were restored in combination with the more functional virtues to create a more luxurious vehicle. Observant of the transition, Sloan recognized that the only way to obtain greater speed and power without increasing the size of the engine was to increase its efficiency. Kettering saw, as few others had, that efficiency could be achieved by solving the problem of knock. Redeploying the efficiency from its originally intended use for conserving fuel, the purpose of the antiknock research became the means of increasing speed and power.

Thus, it was the antiknock research, rather than the copper-cooled engine that revolutionized the car. Solving the problem of knock eliminated the last remaining obstacle to perfecting the internal combustion engine. In the mid-1920s, for the first time, it became possible for automakers to make a quantum leap in the compression ratio of vehicle engines, making them as much as 50 percent more efficient. This new-found power would be used to bring to the middle class the automotive virtues of speed and power, luxury and status that had previously been the exclusive domain of the upper class. Conservation fell to secondary status among automotive virtues. The distant consequences of this turn of events are known to everyone.

In essence, what was perfected was the engine-fuel combination. This was the last missing piece in building the modern automobile. From that point on, the hierarchy of automotive virtues has never changed, except in times of crisis. There would be steady improvements in automobile technology and design, certainly, but almost all of these would be the fulfillment of already-established virtues by refinement of already-existing engineering properties. To the extent that new engineering properties were added — such as air conditioning and automatic transmission — they would be luxuries, not essential elements.

Perfecting the engine-fuel combination also laid to rest any serious discussion of steam and electric-powered vehicles for the next 40 years. In 1924, for the first time since the first National Auto Show in 1900, not one electric or steam passenger vehicle was exhibited. Perfecting the engine-fuel combination also parried any serious challenge by the alcohols as a base fuel for the internal combustion engine until the late 1980s. Only at brief intervals, when farm commodity prices were extremely low, when petroleum supply was in doubt, or when environmental concerns were heightened, did ethanol intrude upon gasoline's motor fuel monopoly.

Fundamental to the discovery of tetraethyl lead was Kettering's insight that the problem of knock was associated with the fuel. Before this, most refiners had accepted nature as they found it: refiners had little ability to improve the chemical constituents of crude oil. One reason the fuel-engine combination had not been perfected before was that it involved two separate manufacturing industries — the automakers and refiners. It was Kettering's sense of vision that bridged between the two industries to solve the problem. Over time, other ways to increase octane would be developed, but tetraethyl lead would remain the cheapest.

But increasing the octane of motor fuel was a one-way street: once automakers began to build engines with compression ratios requiring octane at a higher level than could be derived from crude oil by distillation alone, the auto and its driver became dependent upon the refining industry to produce a gasoline of octane quality that did not exist in nature in the necessary volume. Sloan knew that once automakers introduced high-compression engines that relied on tetraethyl lead there could be no turning back. Since Ethyl held the patents on the cheapest source of octane, GM was virtually guaranteed a profit from every high-compression car sold, if not from the vehicle itself then from selling the additive used in its fuel.

The Kettering Doctrine

The discovery of tetraethyl lead proved to be significant technologically, but another product of the antiknock research that may be even more significant and enduring than lead additive itself is the doctrine that was developed with it. The discovery of tetraethyl lead was the stimulus for a coalescence of public opinion about industrial society.

The term "Sloanism" has been created to describe the policies GM originated in this period. But the term is not fully descriptive. Much of the public image GM created for itself in this period seems attributable to Kettering. Kettering gave nearly two thousand speeches and published numerous articles, which almost always forecast progress and prosperity using tetraethyl lead as living proof of the limitless possibilities. The social philosophies that constitute this body of literature, which can be called the "Kettering Doctrine," became a blueprint for 20th Century ideals.

First, the discovery of tetraethyl lead came to symbolize the social benefits that were possible from industrial research. It dramatically illustrated the idea of "progress through science." Kettering became an influential spokesman for the idea, a 20th Century "Prophet of Progress." Kettering, of course, was not the first hero-inventor in America. Thomas Edison provided the model followed first in the auto industry by Henry Ford. Ford worshiped Edison; Kettering merely imitated him.

An important component of the hero-inventor role was the ability to visualize the direction that invention should take. For example, Ford is recalled as an innovator for his introduction of the Model T and mass production. But Ford himself was not responsible for essential parts of these innovations. Ford did not have the requisite skills to develop the Fordist principles and actually had nothing to do with carrying out the design. And Ford by himself could never have made a success of the Ford Motor Company; it would have failed financially long before he got to the Model T. But what Ford did have was essential: he had a vision, without which there would have been no reason for these innovations to be developed. Ford's vision also applied to those outside his organization: Ford was very concerned about what the public thought about him and his work, and he took charge personally of explaining himself through such books as *My Life and Work* (1922). As a result, the populist image he created lodged in the public mind.

Ford's communication of his vision demonstrated to Sloan and Kettering how important a carefully crafted corporate image was to selling cars. Sloanism, like Fordism, served as both competitive strategy and public image. But the image that had worked for Henry Ford was unacceptable to Sloan and Kettering. First, Sloan believed that a modern corporation must be managed by scientific methods rather than by personality. Sloan had only to look at GM's founder Billy Durant to find evidence of the problems that would come from managing by charisma. Second, Ford's failure to advance the technology of the Model T presented the opportunity to establish a distinctive image for GM, one that trumped the Fordist promise of mass consumption. GM products would constitute more than just basic transportation, they would represent progress through science. But Sloan's cold and analytical personality made him a poor candidate to put a benign face on GM's image. Kettering, by contrast, as GM's chief scientist, was supremely positioned to represent advancement of automotive technology through research. Thus, Sloan and Kettering portrayed themselves as representing technology advancement, which they equated with human progress.

Kettering became GM's advocate for innovation, creating the image of GM as the innovation leader. Kettering was the exception to Sloan's desire for colorless management. His speeches were popular with a wide audience because of his ability to make the details of the most technical issues comprehensible, indeed fascinating, to the ordinary individual. For more than a generation Kettering was the voice of optimism for the technological "wonders of tomorrow."

Recognizing the differences between the Kettering Doctrine and Sloanism explains apparent contradictions in GM policies. While both Sloan and Kettering supported planned obsolescence as a way to stimulate demand, their views diverged as to GM's role. Kettering thought new products should be introduced as early as possible and improved through use, as he did with Ethyl gasoline, because he felt that the ultimate objective of planned obsolescence was to improve the technology. He often stated that the research laboratory was society's change agent, a "procurement department for new ideas." Sloan took a more cautious approach. To Sloan, the technical level of GM's cars was good enough "if our cars were at least equal in design to the best of our competitors in a grade, so that it was not *necessary* to lead in design or run the risk of untried experiments." Sloan left it to others, particularly Chrysler, to take that risk. By contrast with Kettering, Sloan did not make innovation the ultimate goal. These tensions were played out in both of Kettering's endeavors, the copper-cooled engine and tetraethyl lead.

Thus, while Sloan's and Kettering's views differed, the differences did not need to be reconciled publicly. GM's message was that change created the consumer demand that stimulated business and led to innovation. Sloan was willing to portray the annual model year change as a tool for innovation and tout GM as the innovation leader, so long as that did not affect product policy. In time, planned obsolescence came to represent stylistic novelty more than innovation. Thus, the Kettering Doctrine emerged as an essential part of GM's efforts to communicate its image, but was *not necessarily* part of GM's product policy.

Fordism had dramatically illustrated that a consumer product could change the way of life for an entire population. Due in no small part to Kettering's efforts, the idea of progress through science took on a new significance. As GM broadly publicized its innovative policies the Kettering Doctrine became broadly adopted as a corporate doctrine. By the middle of the 20th Century the idea of progress through science had become a predominant theme in American society, and even products that were not revolutionary had to be advertized as "new and improved" to catch a consumer's attention.

By the mid-1920s, the auto industry had grown tremendously, and GM had increased by an even greater amount. In later years, GM would solidify its role as an economic giant, involving a massive shift of national wealth to one company. No wealth transfer of this magnitude could have occurred without public assent to its legitimacy. That is, the public would not have tolerated such a concentration of economic power in the face of a conclusion that it was unjustified.

In an often-quoted passage, Adam Smith had asserted:

> Every individual is continually exerting himself to find out the most advantageous employment for whatever capital he can command. It is his own advantage, indeed, and not that of society, which he has in view. But the study of his own advantage naturally, or rather necessarily leads him to prefer that employment which is most advantageous to society [9].

In other words, society's interests are advanced by the actions of individuals acting in their own self-interest.

In the decades following the Civil War, the majority of Americans subscribed to Adam Smith's laissez faire view, and it seemed not only unnecessary but counterproductive to regulate private capital. The natural resources of the nation were vast and sufficient for all; the century of American expansion had produced a frontier individualism. These tendencies were reinforced by the Fourteenth Amendment to the Constitution which, although enacted to protect civil rights, also came to be used to protect business from regulation.

But laissez faire had not worked out as well as hoped, as it had allowed the unscrupulous to take a disproportionate share of the wealth. Unbridled laissez faire invited its own curbs, which appeared at the federal level in the form of antitrust regulation and rate regulation by a new type of federal agency, the Interstate Commerce Commission.

One has to understand the rise of the automakers as a major turn of public opinion. In the late 19th Century, large corporations arose around the basic industries of steel, coal, railroading and oil. Most of the captains of industry who owned these empires — the so-called robber barons — came to beregarded by the public as economic adversaries of the common man because their monopoly power allowed them to exploit others. Most of them were indeed monopolists at heart and were recognized by the public as such.

Automakers, by contrast, entered the mature stage of their industry with the appearance of competition, and they were able to cloak themselves in a legitimacy the oil men could not. In part, this resulted from a change in the corporate image in the period between 1911 and the mid-1920s. Automakers, especially Henry Ford, were different from the 19th Century industrialists. When Ford introduced the $5 day in 1914, his identification with the farm community was permanently imprinted. So with a recipe of one part economic reality and one part appearance concocted by his publicity staff, Ford built a populist mystique that defied 19th Century models. Ford was able to give the general public the impression that even while he was piling up amazing profits he was pursuing activities that advanced the public interest. The public never lost faith in Ford.

In the Kettering Doctrine both GM and the public were depicted as beneficiaries of free enterprise. Kettering stated, "I am for the double-profit system, a reasonable profit for the manufacturer and a much greater profit for the consumer." Progress through science under the Kettering Doctrine became the way that GM imprinted its identity as a positive element in society. GM was portraying itself as if its interests and those of the public had merged into one common interest. In 1953, GM president Charles Wilson would be restating the obvious when he told the U.S. Senate (to paraphrase) that "What is good for General Motors is good for the U.S." But the reality was that while the actions GM was free to take were good for it, they were not necessarily good for the public. So long as GM could keep up the appearance of mutuality — that its interests and those of the public were harmonious — it would be free to act in its own interest without constraint. The Kettering Doctrine planted the seeds of later controversies that would arise when the public began to wonder whether what was good for GM was always good for the public.

Postscript

Tetraethyl lead came under regulation for its environmental consequences in 1973. Under the Clean Air Act Amendments of 1990, the use of tetraethyl lead is scheduled to be banned at the end of 1995.

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