The History of the Twentieth Century
Episode 250
"An Instinct for the Regrettable"
Transcript

[music: Fanfare]

The 19th century had seen astonishing scientific discoveries, which in turn had led to marvelous new technologies that changed life in the Western world. This process continued into the early twentieth century, but the lesson of the twentieth century was that new technologies bring with them new and unanticipated problems.

Welcome to *The History of the Twentieth Century.*

[music: Opening Theme]

Episode 250. An Instinct for the Regrettable.

Thomas Midgley, Junior, was born on May 18, 1889 in Beaver Falls, Pennsylvania. His family later moved to Columbus, Ohio. In 1911, he graduated from Cornell University with a degree in mechanical engineering.

That same year, 1911, a 35-year-old inventor named Charles Kettering filed a patent for the first practical electric starter for an automobile engine. Kettering had earlier headed the research department at the National Cash Register Company of Dayton, Ohio, where he developed the first electric cash register in 1906. Soon afterward, Kettering and some of his co-workers at the NCR research department started getting together nights and weekends to work on their own private, after-hours project, developing technological improvements for automobiles. The group met at a barn owned by one of their number. They called themselves the "Barn Gang," and called Kettering, who headed the group, "Boss."

In those days, one of the biggest drawbacks of automobiles powered by internal combustion, as opposed to steam or electric batteries, was that they required the operator to manually turn a crank to get the engine started. This process required significant arm and shoulder strength, making it challenging for most women as well as many men to own and drive cars. As you can imagine, it was also inconvenient to have to crank your car to get it started when it was cold outside, or snowing, or pouring rain. Even worse, when the engine caught, sometimes it "kicked" the crank, which could and did injure, and occasionally even kill, people who were starting their cars.

But as I say, in 1911 Boss Kettering and his group succeeded in developing and patenting an electric starting system, one that would use a battery to turn the engine, while also supplying a spark to the cylinders to ignite the gasoline vapors. This system has been used to start automobiles powered by internal combustion ever since, and remains in use in our time. It was a major advance in automotive technology, one that helped to insure that internal combustion would supersede steam or battery power as the main source of propulsion for the modern automobile.

The electric starter also eliminated the gender barrier to driving a car, and by the 1920s, women owning and driving cars would become more or less normal, at least in Western countries, and it has to be regarded as a major advance toward equal status for women.

Boss Kettering was humble about his talent for developing new inventions. He attributed his success mostly to luck, but then famously would add, “I notice the harder I work, the luckier I get.”

From its humble beginnings, the “Barn Gang” evolved into a business, called the Dayton Engineering Laboratories Company, founded in 1909. Kettering would leave NCR to head the new company, which became known by the acronym Delco.

Thomas Midgley, Jr. was hired by Kettering to work at Delco in 1916 and assigned to investigate an important unsolved problem in automotive engine design: knocking. Engine knock, also known as pinging, was first noticed in automobile and aircraft engines in 1914. You’re probably familiar with the term, although you may not know what it is or what causes it. What it is, is a repeated metallic sound that sometimes comes from these engines. What causes it? In 1916, no one knew, though it was widely suspected to be evidence of a design flaw in the internal combustion engines of the time.

It turns out though, that engine knock is caused by improper combustion in the engine. In an internal combustion engine, a mix of fuel and air is compressed, and then ignited by a spark from a spark plug. Ideally, no combustion will take place until the instant the spark plug fires. But when you compress a gas, you also heat it up. Compress the fuel/air mixture too much, and pockets of it begin to detonate too soon, before the spark plug fires. That’s your engine knock. It makes the engine less efficient, and increases wear and tear on the engine parts. It can even damage the engine.

It was Thomas Midgley who came up with the first solution to engine knock: adding iodine to gasoline in his test engine. Midgley, who was not a chemist I want to emphasize here, had this idea that dyeing the gasoline red would help the fuel absorb heat more evenly, or something. This doesn’t sound very likely to me, but Midgley tried it, and it seemed to work, but then

Midgley tried using ethyl iodide, which is colorless, and found that worked just as well. It wasn't the color that made the difference, it was the chemical additive.

What the iodine did was increase the octane rating of the gasoline. I don't want to dig too deeply into the chemistry of this, but basically, octane rating is a measure of how much compression a fuel can take before it detonates. The higher the octane rating, the more compression the fuel can take. Please note that the octane rating is not a measure of the "quality" of the fuel, no matter what my brother-in-law tells you. It is a measure of how much compression it can take. A higher octane fuel is necessary in an engine designed for high compression, and it will give you more power, which is good, especially in an airplane. It can also increase fuel efficiency. A higher octane fuel used in an engine designed for lower compression is nothing but a waste of money. So don't listen to my brother-in-law.

Conversely, a lower octane fuel in an engine designed for lower compression is perfectly fine. (Don't listen to my brother-in-law.) But a lower octane fuel in an engine designed for higher compression gives you knocking, which, as I warned you, increases wear and tear and can potentially damage your engine.

Midgley's research opened the way for a new generation of automobile and aircraft engines with more compression and more power. But here's the catch: what chemical do you want to add to the gasoline to increase the octane rating? It turns out there are a number of possibilities. We already know that iodine and ethyl iodide will work, but these were expensive. So Midgley kept experimenting, testing different chemicals, searching for something more practical and economical. And patentable.

Meanwhile, Kettering sold Delco to United Motors in 1916, about the same time Midgley came on board. In 1918, United Motors was sold to General Motors, and Delco became the automotive electronics subsidiary of GM and would remain so until 1997. Delco doesn't exist anymore, although GM still uses it as a trade name.

In 1920, Thomas Midgley filed a patent application for a mixture of gasoline and ethyl alcohol for use as an antiknock fuel. Ethyl alcohol, or ethanol, is the stuff people drink and get drunk on, see episode 231. In October 1921, Thomas Midgley drove a car with a high-compression engine from Dayton to a conference in Indianapolis. The car was fueled by a mixture of 70% gasoline and 30% ethanol. At the conference, Midgley told the Society of Automotive Engineers that ethyl alcohol had "tremendous advantages." It burned cleaner than gasoline and tolerated higher compression, producing more horsepower.

The use of ethanol in internal combustion was nothing new. Some of the earliest experiments in internal combustion were powered with ethanol. Henry Ford's first car ran on ethanol. Some kinds of racing cars were and are powered by ethanol.

Meanwhile, however, control of General Motors had changed hands. I'll have a lot more to say about the drama around General Motors next week, but for now just know that the founder of the company, William Durant, had been forced out by his erstwhile partner, Pierre du Pont, the patriarch of the family that owned the company of the same name, which manufactured explosives and gunpowder. After the war, du Pont had his company begin branching out into polymers and other chemicals with more peaceful applications. Anyway, he forced Durant out of the company and chose Alfred Sloan as his replacement.

GM's new management was not happy with ethyl alcohol as a solution to the knocking problem. Just about anyone could manufacture ethyl alcohol in their basement, and as you know from episode 232, during the Roaring Twenties, just about anyone did. You can't patent a process so commonplace, and a company like DuPont couldn't expect to make ethanol production into a profit center. And the oil companies didn't like it, either. Designing engines to run on a gasoline-ethanol mixture might be the first step toward all-ethanol vehicles that would cut the oil companies out of the booming automotive market entirely. A small company like GM couldn't afford a feud with somebody like Standard Oil.

GM would not remain a small company for very much longer, but even as a big company, it would continue to seek the goodwill of the oil industry. From the 1920s through the 1970s, the automobile companies and the oil companies would represent the biggest and most profitable corporations in America, and during this period they were sometimes called the Siamese twins of American industry.

Thomas Midgley continued to experiment with other compounds that might increase octane rating. In December 1921, just two months after his trip to Indianapolis where he touted the virtues of ethyl alcohol, Midgley hit upon another possibility: tetraethyl lead.

The tetraethyl lead molecule consists of a lead atom at the center, bound to four ethyl radicals. This chemical had been discovered in the 19th century but was nothing more than a chemistry lab curiosity until Thomas Midgley came across it. Midgley demonstrated that a small quantity of tetraethyl lead, less than one part in a thousand, added to gasoline produced a fuel with an improved octane rating.

This was exactly the kind of additive the industry was looking for. What was so great about tetraethyl lead? Well, it was difficult and dangerous to manufacture, store, and ship, which meant only specialized companies could do the work. New processes had to be designed and tested to manufacture it in quantity, and these new processes could be patented. This meant there was zero risk of losing the business to competing manufacturers. And it only took a tiny amount of tetraethyl lead to give a big octane boost. So although the substance was expensive and difficult to work with, it was economically competitive with simpler chemicals like ethanol.

GM and its partners publicly hailed tetraethyl lead, which they would market under the trade name "Ethyl," as a revolutionary advance in automotive engineering, one that would allow larger, more powerful, and more efficient vehicles. Midgley was promoted as the genius inventor behind this breakthrough. Stories circulated about how Midgley had tested thousands, tens of thousands, of different compounds before discovering tetraethyl lead. Much of this appears to have been advertising puffery. No one knows exactly how long it took Midgley or how many chemicals he tested, because GM has never released his lab records for public inspection, not even in our time. It may well have been that he just got lucky.

No one at GM or its partner corporations had a word to say about Midgley's earlier research into ethyl alcohol.

It's important to note that lead is poisonous. The human body can absorb elemental lead by inhalation or ingestion, and it can absorb tetraethyl lead through the skin. Once inside the body, lead is toxic everywhere. The kidneys and the brain are particularly vulnerable. Lead stays in the body for a long time, so lead poisoning is cumulative. Exposure to just a little bit over a long period can be dangerous, even fatal.

In January 1923, GM had set up a pilot project in Dayton to manufacture tetraethyl lead in commercial quantities. By March, a gas station in Dayton became the first in the world to sell leaded gasoline to consumers. By this time, the prospect of adding lead to gasoline had already raised concerns in the US Public Health Service. The Surgeon General wrote a letter to Pierre du Pont expressing fears that lead spewing from the exhaust pipes of American cars would present a public health hazard. None other than Thomas Midgley himself replied to the Surgeon General on behalf of his employer. Midgley conceded that no experimental work had been done on the possible health risks of lead in gasoline, but expressed the opinion that lead emissions would be so small that "the average street will probably be so free from lead that it will be impossible to detect it…"

Remember this is not based on experimental data, but is merely the gut reaction of one researcher—a researcher with no background in chemistry. Midgley was, I'll remind you, a mechanical engineer by training.

Shortly after writing this letter, Midgley took a medical leave of absence. He himself had gotten sick from lead poisoning through his research. He went to Florida for an extended rest and to take in the fresh, lead-free air. Because of his leave of absence, he'd had to turn down an invitation to speak before the American Chemical Society, which had given him an award for his work on tetraethyl lead.

On Memorial Day 1923, at the eleventh Indianapolis 500, the top three finishers were all fueled by leaded gasoline. That was publicity you couldn't buy. Sales of leaded gasoline soared. During the 1920s, GM supplanted Ford as the world's number one car company. I'll have more to say about that next week, but for now I'll just note that in place of Ford's emphasis on economical, reliable transportation, GM sold snob appeal. Cars that were bigger, faster, newer, more stylish. Leaded gasoline fit right in to this marketing plan. GM touted Ethyl as a modern marvel, a chemical with a unique ability to give gasoline engines greater power, and told car owners they weren't getting their money's worth out of their vehicles unless they filled them with gasoline containing Ethyl.

It fit right into the marketing plans in other ways. Unlike ethanol, which people could make in their basements, tetraethyl lead was very difficult and dangerous to manufacture. GM held the patent on it for now, so that guaranteed a temporary monopoly, but even after the patent expired, competition would be minimal, since few firms had the facilities and the knowhow to manufacture such a dangerous and challenging chemical.

In August, DuPont began producing tetraethyl lead at its plant in Deepwater, New Jersey, just across the Delaware River from Wilmington. To underscore how difficult and dangerous it is to manufacture tetraethyl lead, note that the first death at the plant occurred less than a month after it opened.

By 1924, a number of people within GM, including Thomas Midgley himself, were having second thoughts about tetraethyl lead. But over at DuPont, the chairman pointed out to Alfred Sloan that his company manufactured large quantities of nitroglycerine, which was by any measure a more dangerous product. As for the risk of lead emissions from automobile tailpipes, he pointed out that the amount of lead in question was small in comparison to the amount of lead in lead paint, which at the time was in common use, even in residential settings.

Meanwhile, the demand for leaded gasoline continued to grow, until the DuPont facility was not producing tetraethyl lead fast enough to meet the demand. In August 1924, apparently without the foreknowledge of anyone at DuPont, the Standard Oil Company of New Jersey, known then as Esso, and later as Exxon, began producing tetraethyl lead at its plant in Bayway, New Jersey using a newer and more efficient process that it had patented. Soon General Motors and Esso formed a new joint venture, Ethyl Gasoline Corporation, to manufacture tetraethyl lead under the trade name Ethyl. It was a handy trade name. It evoked ethyl alcohol, although the product was *not* ethyl alcohol, and more to the point, it carefully avoided use of the word "lead."

Within two months, the first worker at the Ethyl plant died. Four others soon followed. About three dozen other workers experienced tremors, hallucinations, mental instability, and other neurological symptoms. Newspapers in nearby New York City took notice, which was a potential PR disaster for the new product. Standard Oil insisted that these incidents were the result of unforeseen accidents. They were pioneering a new process, after all. Thomas Midgley appeared at a press conference in New York City and ostentatiously washed his hands in tetraethyl lead, then dried them on his handkerchief. He told the press that the chemical posed no danger whatsoever. In the years to come, he would repeat this demonstration many times.

In May 1925, the US Surgeon General called a conference in Washington to discuss the public health concerns raised by tetraethyl lead. Two weeks before the conference, Ethyl Corporation announced it was withdrawing its product from the market, pending the outcome of the conference. This was good for the company image, but at the conference itself, the representatives of Ethyl pulled out all the stops to get their product approved. One company official declared tetraethyl lead "a gift from God." He emphasized that it emerged only after ten years of research and was unique in its properties. Both of those claims were pretty broad exaggerations. Three milliliters of tetraethyl lead, added to a gallon of gasoline, he told the conference, would increase fuel efficiency by 50%. Other company officials suggested it could eventually triple a car's gas mileage.

In the end, the Surgeon General's committee recommended the sale of Ethyl should go ahead. The dangers associated with manufacturing the additive could be mitigated, while the risk to public health was uncertain. They also recommended more research into that latter question, though in the years to come, most of that research would be done by investigators paid by the industry.

By the mid 1930s, 90% of the automotive gasoline sold in America was leaded. And the best part was, General Motors got a cut of every gallon sold, no matter what kind of car it went into. In Europe, they were using ethanol to increase the octane rating, but the dominance of American car and oil companies plus aggressive marketing soon won the Europeans over. A key development came in 1935, when Ethyl went into a joint venture with IG Farben, the German chemical firm, to manufacture tetraethyl lead in Germany. Germany was at this time rebuilding its air force, the Luftwaffe, at the time, and access to leaded fuel made possible higher performance aircraft engines which will in turn make the next generation of German military planes the best performing aircraft in Europe.

Thanks, guys.

As for Thomas Midgley, after his success with tetraethyl lead, Boss Kettering set him to work on another problem at the boundary between mechanical engineering and chemistry. This one had to do with refrigeration.

Refrigeration was another modern technological marvel, and we've touched upon it before in this podcast. The first practical refrigeration systems appeared on ships and railroad cars in the 19th century, revolutionizing the food industry and making it possible, for example, for people in Britain to eat beef raised in Australia or Argentina.

The first refrigerator designed for domestic use was developed in the United States in 1913, and by 1916 there were competing brands on the market. One of these was purchased by General Motors in 1919 and rebranded as "Frigidaire." Get it? "Frigid air?" Over the course of the Roaring Twenties, refrigerators replaced iceboxes in millions of American kitchens, and Frigidaire was a major brand—so much so that you often heard the word "Frigidaire" used as a synonym for "refrigerator."

But refrigerators were still something of a luxury item at the time. A major obstacle to bringing refrigeration—and air conditioning—into residential settings was the noxious properties of the chemicals these systems used as their refrigerants. The most commonly used were ammonia, sulfur dioxide, and propane, which are fine as long as they stay inside the closed cooling system like they're supposed to, but these refrigerants eventually leak, creating nasty smells and fire hazards.

Midgley was part of a team assigned the task of identifying a safer alternative refrigerant. They settled on alkyl halides. These are compounds of carbon and halogens. The solution they hit upon in the early 1930s was dichlorodifluoromethane. That's a carbon atom bonded to two chlorine atoms and two fluorine atoms. The compound was brought to market under the brand name "Freon," and it revolutionized refrigeration. Because the atomic bonds in the molecule are particularly strong the chemical is all but inert. It does not explode, it does not burn. It is odorless, nontoxic, and perfectly safe to touch or to inhale. Once again, Thomas Midgley demonstrated the safety of his new discovery by breathing the stuff himself, to no ill effect. Since Freon is heavier than air, he was able to pour a flask of Freon over a candle, which extinguished it.

Freon, and later related chemicals called chlorofluorocarbons, became universal in refrigeration and air conditioning systems. In the decades that followed, refrigerators became everyday kitchen appliances and residential air conditioning became commonplace. Even air conditioning inside automobiles.

Freon's amazing properties made it useful in other applications, such as fire extinguishers. Beginning in the 1940s and through the 1970s, aerosol cans became commonplace, first for insecticides and eventually for all sorts of consumer products, from deodorants to cooking sprays to skin care products to air fresheners. The propellants of choice for all these products were chlorofluorocarbons. Over the same period, leaded gasoline, already standard in Europe and North America, went worldwide.

Thomas Midgley would not live to see his two major inventions conquer the world. He was honored with awards and degrees and elected president of the American Chemical Society. But in 1940, he contracted polio, a dreaded disease that was becoming increasingly common in the United States and Europe over the first half of the century. The disease left Midgley disabled. The intrepid inventor devised a harness and a system of ropes and pulleys that would allow him to get in and out of bed unassisted. Alas, he got himself entangled in the machinery of his own invention and it strangled him in November 1944. He was 55 years old.

[music: Tchaikovsky, *Symphony No. 6*]

It is difficult not to view the tragic death of Thomas Midgley as a metaphor for how even a clever invention, devised with the best of intentions, can have unforeseen, even disastrous, consequences.

For the next couple of decades or so after his death, Midgley was an admired figure in the pantheon of inventors, until subsequent developments began to chip away at his reputation. In 1948, a geochemist named Clair Cameron Patterson began research into the age of the Earth, a question we've discussed before here on the podcast. His chosen method was to measure the ratio of uranium to lead in rock samples. Since uranium decays into lead at a known rate, the ratio should tell you the age of the rock, provided you can measure the amounts of uranium and lead with sufficient precision.

Early in his research, Patterson discovered that his rock samples were so contaminated with atmospheric lead that he couldn't get precise measurements. He was forced to build one of the earliest examples of what we now call a "clean room," a laboratory space with filtered airflow and tight control over what comes into the room in order to exclude lead contamination. In 1956, he published his results, showing that the age of the solar system was about 4.5 billion years, give or take. That was substantially higher than previous estimates, but it is the figure generally accepted even today.

But his discovery of measurable lead contamination led Patterson to investigate lead in the world environment. He determined that surface seawater contained higher concentrations of lead than deep water, indicating an atmospheric source. Core samples of ice from Greenland and Antarctica showed a sharp increase in atmospheric lead beginning about the same time that leaded gasoline was introduced.

By the 1960s, Clair Patterson became perhaps the world's leading authority on lead contamination in the environment. He argued that what were generally considered to be "normal" levels of environmental lead were in fact of human origin, mostly from automobile exhaust. For his efforts, he was targeted by the oil and automotive industries, which questioned his results and attempted to tarnish his reputation. He was shunned by some of his scientific peers.

The rapid growth in the number of automobiles and miles driven in the United States in the 1950s and 1960s also led to concerns over other forms of automotive air pollution. The US Congress passed the Clean Air Act in 1963, with additional amendments in 1965, 1967, and 1970. The 1970 amendments set standards for automotive emissions.

The pollutants of greatest concern at the time were carbon monoxide and unburned hydrocarbons. The major automobile companies in the United States had been pooling their research efforts in pollution control technology, while also arguing that the standards the legislation was requiring them to meet were impossible to achieve. The Federal Trade Commission filed an antitrust action against the four major automobile companies in the US, accusing them of pooling their research not to promote pollution control, but to obstruct it, which led to a 1969 consent agreement under which the companies ended their collaboration.

The technology that allowed new automobiles to meet the 1970 Clean Air Act amendments was the catalytic converter, a device that uses a catalyst to convert carbon monoxide and hydrocarbons in the car exhaust into carbon dioxide and water vapor. By 1975, most new cars sold in the US included this technology.

The catalyst in the earliest catalytic converters was platinum, which is of course an expensive metal. Catalytic converters added a considerable sum to the sticker price of the car. The other problem was that catalytic converters were incompatible with leaded gasoline, because lead in the exhaust coated the platinum catalyst, rendering it ineffective. This required that all gasoline stations in the US begin to offer unleaded gasoline for new cars. A special nozzle and gas tank combination was created so that leaded gasoline pumps could not pump fuel into cars meant to use unleaded fuel.

The US automobile industry fought vigorously against these changes, arguing that catalytic converters were too expensive. They would make automobiles unaffordable, especially when you add in the cost of unleaded fuel, which at the time was more expensive than leaded gasoline. They also argued that without tetraethyl lead, future cars wouldn't achieve the power or the gas mileage Americans were accustomed to. This last argument was particularly disingenuous. Despite the marketing claims, tetraethyl lead was never unique in its ability to raise octane ratings, and in the fifty years since it was introduced, newer additives were developed that raised octane ratings without using lead. And there was always ethanol.

Over the next two decades, the use of leaded gasoline in the US dwindled to almost nothing. It was completely banned in 1996. Other countries followed suit. The European Union banned leaded fuel in 2000. Since then, the United Nations and other international organizations have succeeded in encouraging the phase-out of leaded gasoline worldwide, although millions of tons of lead remain in the soil around the world, a legacy of the days when leaded gasoline was commonplace.

The elimination of lead from gasoline began as ancillary to a different project: reducing tailpipe emissions of carbon monoxide and incompletely burned hydrocarbons. But also in the 1970s, just as unleaded gasoline began to appear at American filling stations, new research on the neurological effects of lead was also emerging. It has been known since ancient times that human beings who work with lead sometimes experience neurological problems, and these can be serious. It even happened to Thomas Midgley. But this new research showed that even very low levels of lead exposure in children could lead to lifelong neurological impairments, including reduced IQ scores, deficits in attention and impulse control, and an increase in violent behavior.

I mentioned earlier that lead was a common ingredient in paint used to paint interior walls of homes in the US and many other countries. This fact was often cited as an argument against eliminating lead in gasoline. What was the point in worrying about lead in our exhaust fumes when we all had lead in our homes? But lead paint had always been a problem. Painters had to be careful working with the stuff; some experienced those neurological problems that are inherent in working with lead. The French actually banned lead in paint used in buildings all the way back in 1909, and a proposal for a global ban on lead paint came up at the League of Nations back in the 1920s, at the same time Thomas Midgley was experimenting with tetraethyl lead, although nothing came of that discussion.

As a result of the new research on the dangers of lead to children, lead paint was banned in the US in 1977 and in the European Union in 2003, and in many other places since. In our time, even in many countries where lead paint remains legal, there are limits on the amount permitted in residential applications.

In the United States, studies have shown that since the 1970s, when lead paint was banned and unleaded gasoline began to supplant leaded gasoline, through until our time, the levels of lead in the blood of Americans has steadily declined.

You know what else has declined?

The US experienced a sharp increase in the rate of violent crime over a 30-year period extending roughly from 1960 through 1990. This became a political issue in the US and led to many policy changes, including increases in police funding and newer and tougher law enforcement methods. The criminal justice system was made harsher. Thousands of new criminal statutes were enacted, and sentences became much longer.

None of these policy changes seemed to impact the crime wave though, until the 1990s, when it abruptly began to recede. And this phenomenon was not unique to the United States. Other countries saw similar increases in crime and violence that began later than in the US, but also lasted longer. Investigation has shown a tight link between the introduction and phase-out of leaded gasoline in a society and a rise and fall in crime rates, with a time lag of about 20 years. In other words, it looks an awful lot like the widespread use of leaded gasoline leads to a generation of children who grow up with higher rates of lead-related neurological impairments which in turn leads to an epidemic of crime and violence. While the claim of a link between lead and crime is not universally accepted, the evidence is pretty strong. A 2011 study from California State University estimated that the elimination of lead from gasoline worldwide significantly increased the overall average global intelligence, resulted in 58 million fewer crimes committed, leading to US$2.4 trillion per year in economic benefits worldwide.

Meanwhile, in 1974, just as the first US automobiles with catalytic converters were rolling off the assembly lines, two chemists at the University of California, Irvine, American Frank Rowland and Mexican Mario Molina, published a paper about Thomas Midgley's other great invention, chlorofluorocarbons, or CFCs. CFCs are uncommonly safe and stable compounds under everyday conditions, but Rowland and Molina showed that when CFCs rose high into the Earth's atmosphere, where they were exposed to ultraviolet radiation, they broke down, releasing chlorine into the atmosphere. This chlorine acts as a catalyst to the destruction of ozone in the Earth's upper atmosphere.

The Earth's ozone layer provides protection to life on the surface of the planet from high-intensity ultraviolet radiation from the sun. A depletion of the ozone in the atmosphere thus has the potential to increase skin cancer in humans and produce a variety of other threats to animals and plants all across the planet.

The chemical and aerosol industries vigorously pushed back against these claims. The chair of the board of DuPont described Rowland and Molina's paper as "science fiction" and "utter nonsense." Pressure was put on the University of California to rein them in. Industry argued that there were no feasible substitutes for CFCs, and a ban on them would make refrigeration and air conditioning prohibitively expensive. Aerosol cans would become a thing of the past.

But researchers took the Rowland-Molina hypothesis seriously and further investigated the issue. In 1985, three British researchers, Joe Farman, Brian Gardiner, and Jon Shanklin, published results showing inexplicably low ozone levels over Antarctica, a so-called "ozone hole," caused by CFCs.

Two years later, the major CFC-producing nations signed a treaty in Montreal, Canada, agreeing to phase out chlorofluorocarbons. The Montreal Protocol has been a huge success, and it is estimated that the damage to Earth's ozone layer will be repaired by the end of the 21st century. Newer, safer refrigerants and propellants have successfully replaced CFCs. We still have refrigerators and air conditioners and aerosol cans. Rowland and Molina and another researcher were awarded a Nobel Prize in 1995 for their work on CFCs and their effect on the Earth's ozone layer.

The elimination of lead and of CFCs from the Earth's atmosphere are two of the biggest success stories in the history of environmental protection, but they have not been kind to the legacy of Thomas Midgley. In the middle of the twentieth century, he was a highly respected inventor, a symbol of how science can make the world a better place.

But the unhappy legacy of his inventions has thoroughly tarnished his posthumous reputation. The American-British science writer Bill Bryson described Midgley as someone with "an instinct for the regrettable that was almost uncanny." American environmental historian John Robert McNeill described Thomas Midgley as having "more impact on the atmosphere than any other single organism in Earth's history." That's quite an epitaph.

And in 2010, *Time* magazine ran an article on "The Fifty Worst Inventions." Both leaded gasoline and chlorofluorocarbons made the list.

We'll have to stop there for today. I thank you for listening, and I'd especially like to thank Amy for her kind donation, and thank you to Tony for becoming a patron of the podcast. Donors and patrons like Amy and Tony help cover the costs of making this show, which in turn keeps the podcast available free for everyone, so my thanks to them and to all of you who have pitched in and helped out. If you'd like to become a patron or make a donation, just visit the website, historyofthetwentiethcentury.com and click on the PayPal or Patreon buttons.

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And I hope you'll join me next week, on *The History of the Twentieth Century,* as we maintain our focus on American business and technology, and specifically on the General Motors Corporation. Henry Ford amazed the world with his mass production of cheap, practical cars, and it made him one of the most famous inventors and richest businessmen in the world. But after the Great War, Ford's company would be overshadowed by General Motors, a company with a completely different marketing strategy. Keeping the consumer dissatisfied, next week, here, on *The History of the Twentieth Century*.

Oh, and one more thing. If the names of Thomas Midgley's bosses, Alfred Sloan and Charles Kettering, sound familiar to you, it may be because of the Sloan-Kettering Institute, now part of the Memorial Sloan Kettering Cancer Center. The Institute was founded with a large donation from Alfred Sloan in 1945, just months after the death of Thomas Midgley. Charles Kettering oversaw the program in its early years.

Sloan and Kettering also oversaw Midgley's work, with all its unhappy, unintended consequences for the health of millions of people, but Sloan-Kettering has since 1945 contributed valuable advances in the treatment of cancer, improving the lives of millions of people. Make of that what you will.

[music: Closing Theme]