Inventing Six Modern Electric Lamps.

"Genius is ninety-nine percent perspiration and one percent inspiration."
(Thomas Edison)

Whatever the percentages, the concept is much the same for inventors today as for Edison. But circumstances have changed. Work is more often done in groups in large laboratories; scientific training is essential; equipment is complex and expensive. Here, we examine some of the differences and similarities between inventing Edison's lamp, and inventing six recent lighting devices.

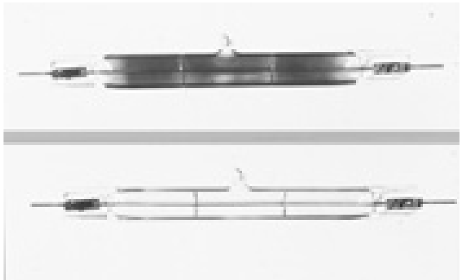
Tungsten Halogen: teamwork	Metal Halide: scientific training	High Pressure Sodium: materials
Compact Fluorescent: manufacturing	Silica Carbide: lone inventor	Sulfur: opportunity

Tungsten Halogen: Working in a Modern Industrial Laboratory

Edison assembled a team of talented assistants for his Menlo Park "invention factory." But he remained the guiding force behind the light bulb effort. From the initial experiments, through design of production equipment, to selling the lamp and its electrical infrastructure, Edison ran the show. Today, most lamps pass from one specialist or group of specialists to another as the original idea becomes a commercial product. Rarely does one individual oversee the entire process.

In 1950, at General Electric's Nela Park facility, Alton Foote led an effort to design a new heat lamp using a small tube of fused quartz rather than a large glass bulb. Foote found that quartz could withstand high heat, but the lamps blackened too quickly to be of use. Tungsten evaporated from the filament and settled on the inside wall of the tube, darkening the lamp.

Machinist turned inventor Elmer Fridrich, with the help of Emmett Wiley, placed some iodine in a quartz lamp and "Eureka! we put it on and instant success ... it was just beautiful." As seen in the image below, iodine cleared the tungsten atoms from the tube wall and returned them to the filament. Despite the initial success, follow-up experiments proved frustrating as some lamps worked and some that appeared identical failed.


Lamp before & after halogen cycle
S.I. image #99-4111

In early 1954 chemist Edward Zubler was assigned to find out just what was happening inside the lamps, and in 1955 engineer Frederick Mosby transferred into the project to begin designing a marketable product. Fridrich and Wiley began playing a reduced role. After about three years of experiments Zubler and Mosby worked out the unique chemical and structural requirements of the lamp, some of which called for new procedures. For example, the tungsten filament wire had to be unusually pure, and this required the participation of engineers at GE's "wire plant."

A "pilot production" facility was set up to provide hand-made experimental lamps and by mid-1958 the team began to feel confident. As Mosby recalled, "Once management decided that we were ready to go beyond the piloting operation, then we called in our manufacturing people. They came in and looked at the lamp and decided what kinds of new designs we had to have in order to make this lamp at higher speeds–and so it just kind of goes out of our hands at that time. We worked very closely with the manufacturing people, but it was now their responsibility to get the equipment made and designed to put into our factories for expanded production."

In 1959, the tungsten halogen lamp was ready to emerge from the lab, bringing more new players into the process. Application engineers designed ways to use the lamps. Marketers began crafting sales pitches and researching needs that the new lamps might meet. This team approach has become typical of modern lamp invention.

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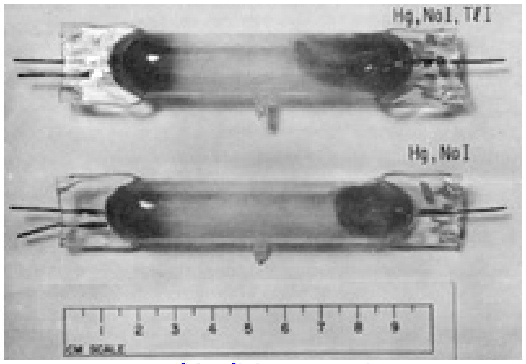
Metal Halide: The Value of Scientific Training

Edison never considered himself a scientist and cared little for theoretical studies. Trial and error experiments gave him the working knowledge he needed, and if some higher math was called for he had Francis Upton on the payroll. Modern lamp inventors have the knowledge inherited from people like Edison, but they have also inherited complex problems not given to easy solutions. Inventing a lamp today calls for advanced scientific and engineering training, both to define problems and to use the highly specialized equipment needed to find solutions.

As early as 1912 Charles Steinmetz had placed metal halide compounds in mercury lamps hoping to improve the lamps' blue-green color. Iodine, bromine and chlorine are all elements known as "halogens" and react chemically with metals to form salts. The physics of electrical discharges and the chemistry of metal halides turned out to be quite complex, and practical lamps were not made until the late 1950s.

By the 1950s, mercury vapor lamps were common and the subject of much research. In West Germany, Otto Neunhoeffer and Paul Schultz explored the use of halogens to combat electrode evaporation. Bernard Kühl and Horst Krense also tried halogens in a lamp and filed for a patent in August 1960. However, Osram had introduced an improved mercury lamp (designated H-33) without halides in 1959. The H- 33 lasted longer and was more efficient than older designs, and may have tempered commercial willingness to quickly introduce yet another improved mercury lamp.



Metal halide arc tubes
S.I. image #99-4074

At this same time, American physicist Gilbert Reiling was also experimenting with metal halides and mercury lamps. His work at General Electric's Research Laboratory involved a mix of theoretical studies and experimentation. Reiling was able to bring a high level of expertise to bear on the problem. "I had 11 years of college mathematics, from topography to matrices to tensor [states] - everything you could possibly mention in the field of mathematics, and you need that for the physics. I had made some thermodynamic calculations that showed that, with sodium iodide, the iodine was so powerful that sodium would not attack the quartz [envelope]. That's what so many people worried about, that these alkali metals were just going to chew up the envelope, but it turned out that the thermodynamics showed that it wouldn't, and it was that idea that really made this work."

Reiling's experiments with sodium and thallium (see lamps above) were promising enough that in June 1960 he reported to GE, "these lamps appear to have a higher luminous efficiency than the mercury lamp and the possibility for better color rendition." In September the lab's research director C. Guy Suits wrote to GE's Chairman Ralph Cordiner to tell him of the new lamp. Suits reported that, although the lamp produced white light "through a complex mechanism which our scientists are still studying in detail,... it now appears that little change will be required in manufacturing the new lamps other than simply adding a scientifically determined 'pinch' of the optimum compound." GE publicly announced the metal halide lamp in late 1962 and used it at the 1964 World's Fair.

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High Pressure Sodium: Studying Materials

Edison spent almost a year trying to develop a platinum filament for his lamp. The material would not burn up in air, but making it give light without melting proved difficult. Eventually Edison return to experimenting with carbon filaments, and he and his team baked hundreds of materials before settling on bamboo for their commercial product. The choice of materials is no less important today. Modern inventors simply have many more possibilities to chose from due to the great number of artificial materials unavailable a century ago.

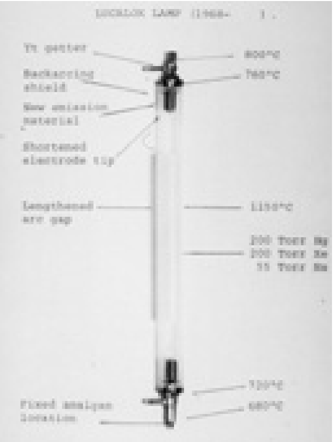
Low-pressure sodium (LPS) lamps were developed in Europe early in the 1930s. Because sodium was very corrosive, LPS lamps needed special glass and very stable temperatures to operate. These factors led to complex glass-work, Dewar-type housings, and large fixtures. Research in the 1920s indicated that increasing the sodium's pressure would improve the lamps' poor color, but no practical material could be found that resisted sodium corrosion at the higher pressures.

After World War II, the GE Research Laboratory in Schenectady began a program to explore the properties of ceramics. Under the direction of chemist Joseph Burke, the program was designed to provide an understanding of ceramic processes. There was no particular product goal in mind, just fundamental research into a little known area.

In 1955 Robert Coble, a recent graduate from M.I.T., joined the team. A series of experiments ensued with polycrystalline aluminum oxide (PCA). Coble added magnesium to the mix, making a material Burke described as "more nearly transparent than had ever been hoped for. Actually, it was more nearly translucent. ... the material appears similar to a slightly frosted glass–but light transmission is from 90-95%."

Metallurgists and ceramicists worked on improving processing techniques needed to produce the new material (now called "Lucalox" for Trans**luc**ent **Al**uminum **Ox**ide) consistently, mainly by determining the manufacturing parameters. George Inman, a senior manager of GE's Nela Park lighting works in Cleveland heard of the PCA research during a trip to Schenectady in 1956 and directed engineer William Louden to begin assessing the possibilities of making a new lamp. In late 1957, Inman sent chemical engineer Nelson Grimm to Schenectady to learn about Lucalox and its manufacture. Grimm returned to Nela Park and established a "pilot-plant scale operation" that began providing tubes of the translucent material to Nela's lamp designers in 1958.

Physical chemist Kurt Schmidt began experimenting with different fill-gasses and in August 1959 filed for a patent on "Metal Vapor Lamps" that included sodium. Still, the lamps were not ready for sale. A difficult problem lay in sealing the ceramic tubes, since they could not be pinched shut like hot glass. Few sealing materials would stick to the new ceramic, and those that did needed to withstand the high operating temperatures and pressures of the lamp.



Lucalox tube
S.I. image #99-4125

The task of designing the seals fell to Louden who later recalled, "The first seals that we made to Lucalox with metal were very short lived and we experimented for a long time with various methods of sealing. We got life out to 2000 hours, and at that point everybody began to recognize that we had something that might be commercially feasible." Niobium was chosen for the seal and made into a cap that expanded at nearly the same rate as aluminum oxide. However, niobium was a fairly exotic element, and new methods of working it had to be devised. Also, a material had to be found to serve as a "frit" (or caulking) between the niobium cap and the equally exotic ceramic tube.

In 1962 GE unveiled the new high-pressure sodium (HPS) lamp. A reporter covering the unveiling noted some bantering between Louden and Schmidt.
" 'He was destroying things as soon as they were made,' said the electrical engineer."
" 'He couldn't make them tough enough,' said the physicist."

Though reported as a joking exchange, the underlying situation was serious. The HPS lamp was not sold until 1965 and was redesigned in 1967. Continued materials research since that time has resulted in: clear ceramic tubes (Westinghouse & Corning, 1976); very high pressure lamps (Philips 1986); and "unsaturated lamps" (Philips, Sylvania 1993). In 1997, ceramic tubes were adapted to metal halide lamps.

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Compact Fluorescent: The Challenge of Manufacturing

Inventing a product often calls for inventing manufacturing equipment and processes. Many Edison patents described improved ways of making lamps. To achieve his price goals, Edison needed mass-produced light bulbs rather than a hand-crafted product. Desire to boost production machine efficiency has often motivated design changes in lamps. Conversely, new lamps requiring complex production techniques have often been shelved as uneconomical. In the 1970s, many inventors proposed designs for efficient compact fluorescent lamps (CFL). Most of these designs worked in the lab. However, most were considered too expensive to mass-produce.

Below are a few of those designs.

John Campbell (General Electric) "Sequential Switching Lamp," 1972. (See U.S. patent # 3,609,436.) Campbell's work on high-frequency fluorescent lamp ballasts in the 1950s led to this design. The lamp contained multiple electrodes, each activated in quick sequence in its own arc-path. The switching circuitry and the glass-work were deemed too complex for mass production.

William Roche (GTE-Sylvania) "Short Arc Lamp," 1974. (See U.S. patent # 3,849,699.) Roche described this lamp in a 1996 interview: "In some of the early days we were trying to develop a ballast-less fluorescent lamp. How could we compact the lamp and eliminate the ballast? [We thought] maybe the ballast wasn't all that bad if we could miniaturize it and tuck it away in the base. This lamp's construction had a filament running the length of the lamp to serve as an ignition aid. The problem is that they were not efficient, the shortness of the arc was one major problem. [In] the short-arc, high-current was required to generate the power, and the high-current in the ballast created losses within the electronics. It proved not to be feasible."

John Anderson (GE) "Solenoidal Electric Field Lamp" and Donald Hollister (Lighting Technology Corporation) "Litek Lamp," mid 1970s. Electrodes are responsible for much of the energy lost in a fluorescent lamp and are usually the first part of the lamp to fail. Both Anderson and Hollister designed small "electrodeless" lamps that operated with high-frequency radio waves instead of electrodes. The electronic components available at the time were expensive and generated too much heat, and neither lamp made it to market. However, in the 1990s, Philips, GE, and Osram-Sylvania all began selling electrodeless fluorescent lamps.

R. Gaines Young (Westinghouse), and Harald Whiting (GE) "Partitioned Lamps," late 1970s. Due to the physics of fluorescent lamps, longer tubes mean higher energy efficiency. One way around this is to create a maze-like path for the electrical arc using glass partitions within a short bulb. Young, Witting, and others patented many variations on this theme, but the glass-work for all proved too complex for high-speed manufacture.

Jan Hasker (Philips) "Recombinant Structure Lamp," 1976. (See U.S. patent #4,101,185). Hasker developed compact fluorescent lamps filled very loosely with glass fibers. These fibers altered the properties of the electrical current flowing inside the lamp, boosting light output without reducing energy efficiency. Though his experiments were promising, Hasker wrote that, "before any practical applications can be realized, technological problems concerning the manufacture of the recombination structure ... should be solved." Hasker's was only one of the CFL designs being developed by Philips, and the company chose not to pursue the lamp, partly due to manufacturing concerns.

Spiral CFL
S.I. image #lar2-2d1

Edward Hammer (GE) "Spiral Lamp," 1976. Hammer's idea (at left) was to take a long, thin fluorescent tube and bend it into a spiral shape. This not only allowed for a long electrical arc, but also simulated the optical properties of a frosted incandescent lamp. Existing lamp machinery had difficulty making the fragile spiral, and GE felt that new machinery would be too expensive, so they shelved the design. However, spiral lamps appeared on the market in 1995 as other manufacturers decided to see if the design could be competitive.

Leo Gross and Merrill Skeist (Spellman Electronics) "Magnetic Arc-Spreading Lamp," 1980. An energized coil of wire in the middle of a cylinder-shaped lamp generated a magnetic field. The field expanded the electrical arc inside the lamp, activating a greater area of phosphors. Prototypes included both cylindrical lamps and a hemispherical unit. According to Skeist, "we achieved 15% improved efficiency" over other CFL designs, at which point, "many companies expressed interest." But the glass envelope proved too expensive to make.

Successful designs from Philips and Westinghouse, and CFLs from other manufacturers that followed, required substantial investment in new production machinery. This was a major reason why the initial price of these lamps was rather high (about $15 in the early 1980s–which would be about $30 now). Large orders from governments and electric utilities, who then offered the lamps to customers at sharply reduced prices, gave producers an incentive to make the needed investments.

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Silicon Carbide: The Lone Inventor

Americans hold a special place in their hearts for the "garage inventor"–someone who, without an expensive laboratory or a large staff of assistants, proceeds to dazzle everyone with a marvelous new gadget. Edison and his team at Menlo Park really don't fit this image, and given the electrical equipment needed for lamp experiments neither did most others of that era. The training and equipment needed for inventing electric lights still serves as a hurdle that lone inventors must overcome. But a large lab is not required for inspiration; that can come from a high school project.

Research to find a better filament has been a part of incandescent lamp history since the beginning. Edison and many other inventors labored to find a suitable material. By the 1920s tungsten became the filament of choice and has remained so to this day. As production techniques became more sophisticated, most researchers turned to improving, rather than replacing, tungsten filaments.

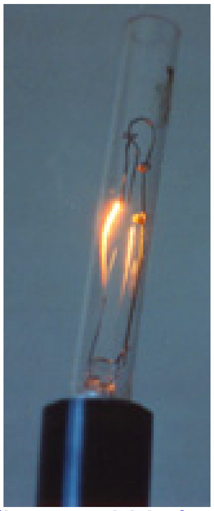
In 1987, John Milewski, Sr. found himself with an interesting situation. His son, Peter, had decided to investigate the electrical properties of single crystal "whiskers" of silicon carbide (SiC) for a high school science fair. Peter's goal was to determine if the ceramic material would make good heating elements. His choice of projects was influenced by his father's career. The elder Milewski (with a Ph.D. in ceramic engineering) worked at Los Alamos National Laboratory, exploring the use of SiC whiskers as structural reinforcement for graphite objects.

John Sr. began assisting his son with some excess silicon carbide left over from lab experiments. SiC could withstand 1500-1600ºC, making it a good candidate for a heating element. As they increased the temperature, they found that the whiskers glowed, not totally unexpected since many materials radiate light at high temperature. What surprised them was how fast light production increased as temperature rose. They redirected the project from developing a heating element to evaluating SiC's potential as a lamp filament. Using surplus equipment purchased from Los Alamos, father and son began making light bulbs in their living room.

Though hampered by their inability to create a very high vacuum in their lamps, the comparison of SiC to tungsten yielded interesting results. Peter's project took third place at the science fair, but the consolation prize was U.S. Patent #4,864,186 issued to the Milewskis in 1989. By that time, Peter had entered North Carolina State University, and John Sr. had retired from Los Alamos and established Superkinetic Inc. with $83,000 ($30,000 for patents, $50,000 for equipment). John's goal was to improve the whiskers and seek "more perfect crystals" by initiating experiments with hafnium carbide (HfC). He moved the work out of his home and into a lab at the

University of New Mexico.

Unlike corporate researchers, Milewski had to mix fund raising with experimenting. In April 1991, he submitted sample SiC lamps like the one at right to the National Institute of Standards and Technology (NIST) for evaluation and received a favorable review. Later that year he obtained funding from the Electric Power Research Institute (EPRI). The EPRI funds allowed Milewski to improve his equipment and make filaments 5 microns in diameter and 3 mm long.



Silicon carbide lamp
S.I. image #99-4100

However, SiC crystals take around 16 hours to grow, while HfC crystals take 35-40 hours. Problems arose in keeping oven conditions constant for that length of time, particularly with the surplus equipment being used. Milewski and company were building their own equipment or picking up surplus materials from Los Alamos and Sandia National Labs. Crystal-growth processes became the main problem standing between them and success.

In 1993 the EPRI money ran out, but Superkinetic was able to land a $100,000 grant from the joint NIST-DOE Energy-Related Invention Program. This allowed production of filaments up to 7 micron diameter and 7mm length. The funding only lasted one year, however, and Milewski took a page from Edison's book by expanding research and development in his company to include more immediately marketable products. To date, the ceramic filament lamp remains in the laboratory.

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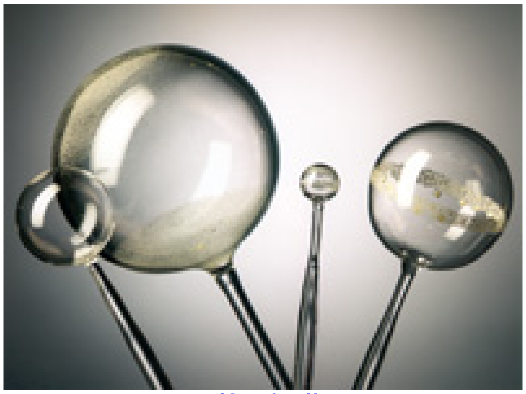
Sulfur: Opportunity in a Non-Lighting Company

George Westinghouse's company became the #2 lamp maker in the U.S., but he did not start out making lamps. Westinghouse invented a railroad air-brake in 1867 and then diversified into electrical railroad devices and more generalized electrical equipment including light bulbs. Invention still occasionally appears from an unlooked-for direction. A breakthrough may require an approach that runs counter to conventional wisdom. Sometimes an answer that requires a large mental leap from an inventor close to a technology may only be a small step for another inventor concerned with a different technology. The development of a microwave-powered light bulb provides a case in point.

In 1990 Fusion Systems was a small company with a successful, highly specialized product. Founded by "four scientists and an engineer," the company marketed an innovative ultraviolet (UV) lighting system powered by microwaves. Introduced in 1976, the system found favor with industrial customers who needed a fast and efficient way to cure inks. A major brewery, for example, purchased the system for applying labels to beer cans.

In 1980 and again in 1986, engineer Michael Ury, physicist Charles Wood, and their colleagues experimented with adapting their UV system to produce visible light. Discharge lamps have traditionally been hindered by the need for electrodes to support an electric arc. Tungsten electrodes are most common, so materials that might erode tungsten can't be used in the lamp and care must be taken to not melt the electrodes. Fusion's UV lamp side-stepped this problem by eliminating the electrodes entirely. Microwave energy was focused on the lamp to energize the discharge. This opened the way for experiments with non-traditional materials, including sulfur.

In 1980 Ury and Wood tried placing sulfur in their linear UV lamp without success. One lamp "blew up," and they shelved the idea. By 1986 they had improved the basic design of the UV lamp by replacing the linear tube with a rotating sphere. Ury decided to try making an electrodeless metal-halide lamp that might be useful in motion picture lighting. The design had color problems, and this project also was shelved.


Sulfur bulbs
S.I. image #lar2-2f1

Ury recalled the sulfur experiments in 1990 and directed engineer Jim Dolan to test the element in the spherical lamp. At 16:57:53 (4:57 pm) on 16 July 1990, a computer print-out showed the inventors what they hoped for: a good visible spectrum with little UV or infrared. They began setting up "crude" lamps in the Fusion production facility in order to learn more about the new light source. They also tested variations of the bulb, such as the different diameter spheres seen here.

After a year of tests, Ury learned of a new optical plastic based on the work of Lorne Whitehead at the University of British Columbia. "Light Pipes" with an internal coating of the plastic would be a perfect way to distribute the light produced by the sulfur bulb. But a demonstration of the technology would be needed.

Lee Anderson, lighting product manager at the Department of Energy heard about the sulfur bulb and saw the invention's potential as an energy saver. He arranged for two high profile public demonstrations of the new technology: outdoors at DOE's Washington headquarters, and inside the most visited museum in the world, the

Smithsonian's National Air & Space Museum. Though he realized that failure would be impossible to hide, Ury agreed to the plan.

The installations proved successful, and the lighting industry began to take sulfur lamps more seriously. Commercial units have been placed on the market. While still not widely adopted, several fixture companies have produced designs that can use the lamp. Whitehead's light-pipe technology has seen a bit more success as several companies have coupled conventional metal halide lamps to them. The long term success or failure of both sulfur lamps and light pipes, of course, remains to be seen.

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To Promoting Modern Lamps

To Inventing Edison's Lamp

To 19th Century Hall

To 20th Century Hall

To Guest Lounge