How the Dynamo, the Arc and Incandescent Lights, and the Grid First Electrified the Modern World

Part 2 of 3 Parts

Thomas Edison's 'One-Machine' Vision: The Birth of the Electric Grid

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INTRODUCTION

In 2000, the US National Academy of Engineering selected the twenty most important engineering achievements of the 20th century. Electrification was at the top of the list. Almost all the other achievements selected – whether the automobile or the airplane, the computer or the Internet – crucially depended on electrification. Electrification had gotten under way well before the 20th century however, with advent of outdoor arc lighting, mainly for city streets and large public buildings in the 1870s. Edison was inspired by a widespread yearning for reliable, safe, on-demand electric light for homes and businesses, where the arc light was unsuitable due to its high voltage and extreme brightness. In September 1878, Edison decided to build and launch the world's first electric grid in lower Manhattan's financial and media district. Four years later, his Pearl Street grid supplied the power to light neighboring residences, businesses, and factories in that small "first district" center of New York's elite class. In doing so, it gave birth to the nation's first electric grids and paved the way for worldwide electrification during the first decades of the 20th century.

EDISON'S "ONE MACHINE" VISION

After a "grueling year perfecting and then promoting his most dazzling invention yet, the tinfoil phonograph," Edison accepted an invitation from friends in mid-1878 to go camping and hunting in the American West and take a "break from the round-the-clock hustle" at his Menlo Park invention factory. Enroute, Edison was inspired by Brush's arc lights in Ohio. When he returned East, "he was consumed with the idea of supplying electricity over a network from a central generating station … He wanted to illuminate entire cities" [1]. Almost immediately on his return, his ambition was intensified by an early September visit to see American inventors Moses Farmer's and William Wallace's new dynamo-and-arc-lamp system "that lit up their whole line of eight arc lights at one time" inside Wallace's workshop in Ansonia, Connecticut. As he explored their setup, "Edison was …

afire with excitement," and wagered a bet with Wallace: *"I believe I can beat you making the electric light. I do not think you're working in the right direction"* [2].

Wallace, having already spent years on the electric light's many technical challenges, accepted the latecomer's wager. Edison later wrote of the visit to Wallace's foundry: *"I saw for the first time everything in practical operation. It was all before me. The thing had not gone so far but that I had a chance. I saw that what had been done had never been made practically useful. The intense light had not been subdivided so that it could be brought into private houses"* [3]. Edison understood that "the huge market opportunity was not in arc lighting, but in creating a less intense light source that could be used in any room" [4].

Within a week of his wager with Wallace, Edison told a reporter visiting him in his Menlo Park lab, *"I can light the entire lower part of New York city, using a 500 horse power engine ... the same wire that brings light to you ... will also bring power and heat"* [5]. This was not mere braggadocio. Edison did not just possess a vision, as had Bell and Morse before him, but the experience to know his vision would cost a lot of money to bring to fruition. He wanted to alert his financial sources, who just happened to work in lower Manhattan where he now promised the miracle of indoor lighting would be born. Within a month, he organized the Edison Electric Light Company and began the process of raising capital for his revolutionary venture.

Edison would eventually raise and spend almost $500,000 to realize his vision – a vast sum for his time.

Edison had participated in the growth and development of one of the world's largest industrial enterprises, the electromagnetic telegraph, starting from the ground up as a telegraph operator, and he participated in the chaotic birth of the telephone [6]. By the time he conceived of lighting homes and businesses with an incandescent bulb, he thought in terms of technological systems, as opposed to singular breakthrough inventions, stating that *"all parts of the system must be constructed with reference to all other parts, since, in one sense, all the parts form one machine"* [7].

The model for Edison's electric light system already existed and was clearly in his mind. When a reporter visited him in mid-September 1878, the journalist wrote that Edison had remarked that the gas light industry's "pipes would serve as ideal conduits for the new electric wires" [8]. Conceptually, the long-established coal-gas plant was the future electric power station, its underground pipes, electricity's wire conduits. Urban Americans had been using gas lighting since the 1840s. “Light … had already become a centralized utility. Edison’s challenge was to replace the gaslight systems with electric ones” [9]. Of course, Edison was well aware of the widely acknowledged shortfalls of gaslight, which he himself deemed “barbaric.” The glass globes of gas fixtures, typically wall-mounted, had to be constantly cleaned, and scrupulously lit and extinguished whenever they were used. Gaslight was both dirty and dangerous: “It sucked the oxygen out of rooms, gave off toxic fumes, blackened walls and soiled curtains, heated the air, and had an unnerving tendency to cause large and deadly explosions” [10].

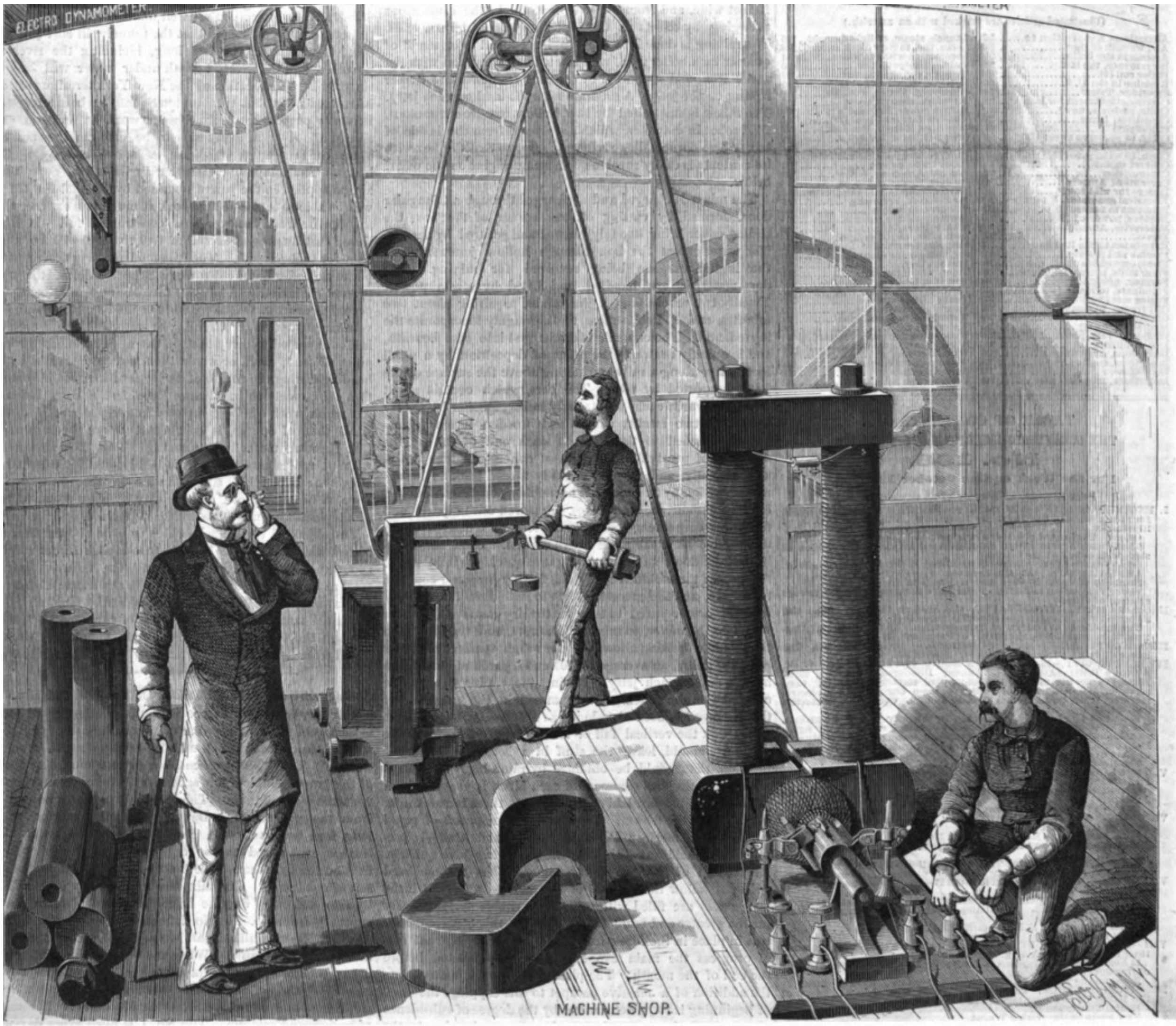
The gas light industry’s problems aside, Edison’s “one-machine” vision was daunting, and the more he carefully studied the gas industry in the fall of 1878, the more he began to understand just how daunting. “A single telephone,” or for that matter a telegraph, “could be invented by a single individual,” or by individual duos like Cooke and Wheatstone, Morse and Vail, or Bell and Watson, but “Edison’s network of power stations required dozens of synchronous developments in switches, fuses, power lines, underground insulators,” and much else besides [11]. The relentless, meticulous improvement of diverse component technologies, as well as de novo technological breakthroughs, required the creative input of many sorts of technical competence.

Figure 1. Edison is seated in the center wearing a hat, directly facing the camera, along with members of his team at the Menlo Park lab – the 'Invention Factory' – in February 1880. SOURCE: http://www.hevac-heritage.org/built_environment/pioneers_revisited/surnames_a-o/edison.pdf

To begin, the Edison team had to develop a dynamo powerful enough to light thousands of lamps safely and efficiently; to design electric circuits, fuses, and junction boxes that would permit electricity to continuously flow to all lamps in the system without interruption, even when some portion of the system's lamps failed; to develop voltage regulators to provide uniform 110-volt current to reach into customers' homes and factories; to create a filament that could burn brightly and yet last for hundreds or more hours (Edison termed this particular task "the real puzzler"); to give the customer or end-user virtually effortless control of their own lights; and to accurately meter the current being used by each customer. Finally, Edison had to do all this for a price competitive with the long-established, proven technology of gaslight.

INVENTING THE INCANDESCENT LIGHT SYSTEM

After experimenting with various arc-lamp dynamos in the fall of 1878, Edison and his top assistants decided they were not adequate for incandescent lighting. By late April 1879, they had "devised a superior dynamo … the 'long-legged Mary-Ann'. Edison's machine had a pair of three-foot-tall iron poles (hence the legs)" between which spun "*a powerful, oversized magnet,*" in Edison's words, the armature or rotor, that served as "*a concentrated source of Faraday's lines of magnetic force*" [12]. As a student of Faraday's work, Edison believed the more lines of force of the stationary stator magnet that were cut by the electromagnetic rotor, the greater the dynamo's power output. The 'Mary-Ann' was capable of lighting hundreds of incandescent lights.



EDISON'S ELECTRIC GENERATOR.—[See page 242.]

Figure 2. Edison’s new ‘Mary-Ann’ dynamo with engineers at work testing it, and a visiting onlooker, in Edison’s Machine Works shop on lower Manhattan’s Goerck Street. SOURCE: https://www.scientificamerican.com/magazine/sa/1879/10-18/

The incandescent light bulb itself proved to be an extremely difficult technical problem, as Edison knew it would. It had proved so for 75 years, ever since Humphrey Davy first demonstrated it in 1802, using his “battery of immense size” in the basement of London’s Royal Institution to run a powerful current through a thin strip of heat-resistant platinum. Unlike his later arc-light demonstration, the light generated by the platinum strip was not very bright, nor did the strip last very long. In experiments after Davy’s filaments continued to catch fire and elude inventors’ best efforts to discover a working example, one that could endure the extreme heat generated by electric current in the filament without self-extinguishing in the presence of oxygen.

The problem of air (that is, of oxygen) required a solution. In Davy's time, a suitable vacuum pump to remove adequate quantities of air around an enclosed filament did not exist. For fifty years, little progress was made. Then, in 1855 a German glassblower named Heinrich Geissler developed a superior vacuum pump, which was improved in 1862. Three years later the German chemist Hermann Sprengel invented the valveless mercury air pump, "a simple and robust device capable of reducing the pressure in a chamber to one millionth of an atmosphere, thus eliminating almost all the oxygen responsible for the combustion." After Sprengel's invention the "search for good bulbs gained new impetus and by the late 1870s" several inventors were close to patenting workable incandescent lights [13]. By the end of the decade Edison was competing in a crowded field.

In fall 1879 Edison's team had improved on Geissler's and Spengler's vacuum pumps, combining the two designs to take advantage of the greater vacating speed of the Geissler pump and the greater vacuum provided by the Spengler pump. Edison hired an expert glassblower, a former Geissler student, to help make "small glass containers in a shape that reminded onlookers of tulip bulbs" – hence the name light "bulb" [14]. Edison, as well as other inventors, soon realized that "filaments contained residual or occluded gases that were released when heated," causing them to fail. "Continuing to evacuate bulbs while heating the filament ultimately resolved the difficulty" [15]. By late 1879, the Edison team "had small glass bulbs that held barely one-millionth air as much air as the ordinary atmosphere" [16].

But the vacuum was only a partial solution to the technical challenge of long-lasting incandescence. "Very early on, Edison had realized that – contrary to common electrical wisdom – he should be seeking to create incandescence with a very high-resistance material" [17]. Increasing resistance would reduce the amount energy needed to heat a filament to incandescence. Further, the thinner the wire, the greater the resistance. Greater resistance and thinner wires would reduce the amount of copper required, as well as the voltage and amperage needed to run Edison's "machine," with its myriad wires and thousands of individual light bulbs. He would, as he had boasted, "subdivide" the "intense light" of the high-voltage arc-lamp by reducing the voltage or power requirement of each bulb in his system.

Edison understood "that the only way to diminish the horrific cost of copper wire for transmission," the single most significant expense of his entire electric power system, “was to run very low currents through thin copper wires … [he] calculated that if he was going to run a low current (of 1 or 2 amps) through his thin copper wires to save money, he would have to develop a high-resistance light bulb (200 ohms) operating at a relatively low voltage (110 volts)” to make his system work [18]. A high-resistance filament would prove essential to Edison’s low-amperage, moderate-voltage system comprised of thousands of small, individual lights.

The lab’s constant experiments with high-resistance-but-fragile metal filaments gave way to experiments with less electrically fragile high-resistance cotton, paper, cork, and other carbon-based materials. Carbon could withstand heat and cast impressive light without degrading. Within six months of creating the Mary-Ann dynamo the Edison team finally hit upon carbonized cotton thread – a thread slowly baked until its extraneous elements were gasified, rendering it a nearly pure carbon structure – that burned for three or four hours without interruption. After several more trials the team produced another version that “glowed through the night … and when the bulb finally burned out about fourteen hours later, they felt certain that the fundamental problem had been solved … Edison had the proof he needed that his system would work” [19]. In early November Edison filed for his first of many incandescent light patents, this one utilizing carbonized thread.

The search for an even better filament continued until the team “‘ended up taking Bristol board, and stamping it out in a horseshoe shape that would be baked in an oven overnight, turning it into carbon. Then using jeweler’s tools ... [they] would secure it in a couple of tiny clamps inside the lamp’” [20]. This proved the best candidate – just in time for the New Year’s Eve demonstration. Bulbs were quickly produced for the occasion.

On December 21, 1879, the *New York Herald* ran a full-page story on the successful illumination of the lab complex: “*Edison’s electric light ... is produced from a tiny strip of paper ... Through this tiny strip of paper is passed an electric current, and the result is a bright, beautiful light, like the mellow sunset of an Italian autumn*.” [italics] Within a day, “flocks of electricity sightseers crowded off specially scheduled Pennsylvania Railroad trains or pulled up in the crudest of farm wagons and the most luxurious of broughams, carriages equipped with coachmen and gleaming pairs … the visitors would head through the dark toward the bright laboratory, there to push through and gaze in awe at the magical display.” Ten days later, at the official unveiling, “three thousand people poured in to Menlo Park, ignoring the stormy weather, to see the miracle of incandescence” [21].

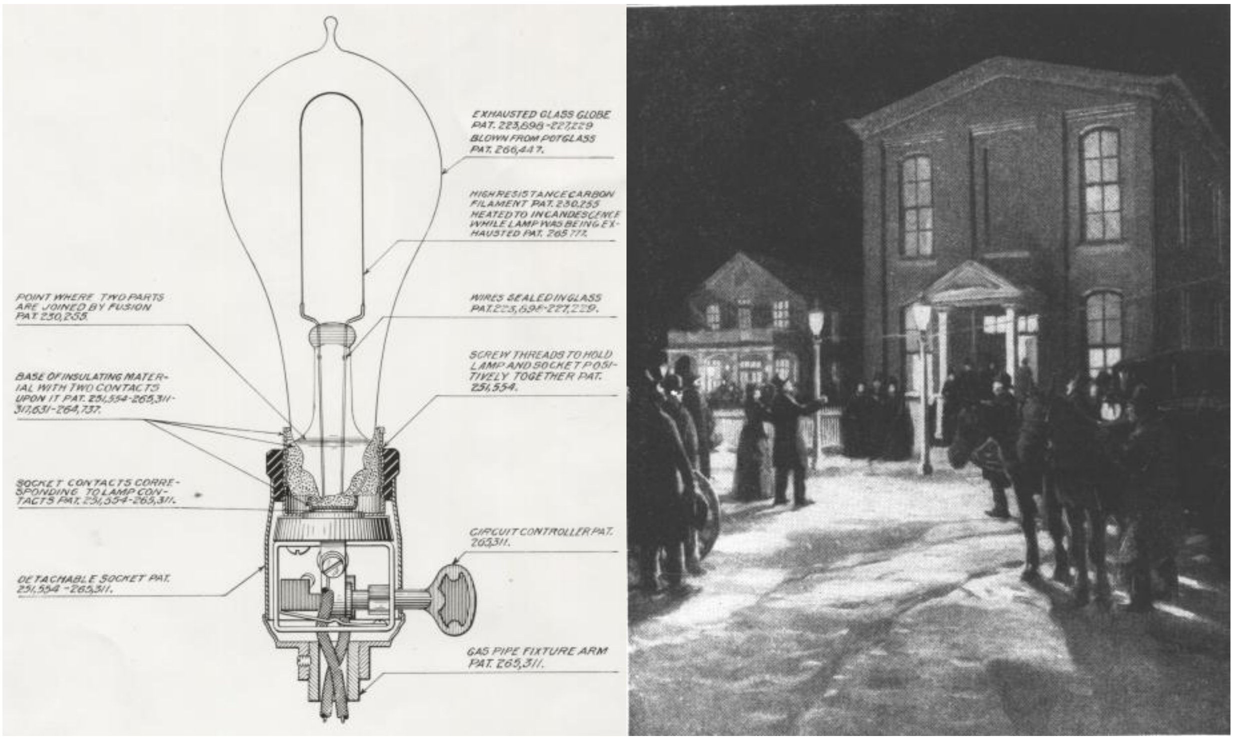


Figure 3. Left side shows the patented innovations that made Edison’s lamp and socket a universally successful invention, while the right side is an illustration originally titled “When the World Came to Menlo Park,” published in Francis Jehl’s memoir *Menlo Park Reminiscences*.
SOURCES: (left) https://www.gutenberg.org/files/820/820-h/820-h.htm; (right) https://americanhistory.si.edu/blog/edisons-light-bulb-turns-135

The “Wizard of Menlo Park” was thirty-two years old when, led by JP Morgan, Wall Street’s coffers opened for him once again early in 1880. Edison doubled his workforce to sixty men. Flush with his first public electric lighting success, Edison’s next public demonstration would illuminate Menlo Park with four hundred incandescent lights along eight miles of streets and pathways. Edison’s goal was to have Menlo Park ready for a convincing Christmas Holidays’ demonstration for his New York City investors and the city’s aldermen, whose blessing he would need to proceed with digging up 18 miles of “subways” for conduits in the First District.

Edison knew that every single component of his system needed major improvements, and to compete with the gas companies, his system’s operating costs had to be constantly weighed and kept in check. The project bordered on the Herculean. It included hand digging an eight-mile-long “system of long, narrow ditches that fanned out from the direct current generating station, [and] ran along Menlo Park's few muddy streets, and then headed out to the surrounding fields" where lampposts would sport individual lights. These trenches, called "subways," would be filled with "narrow wooden conductor boxes, which were coated with tar to protect against moisture and decay and then enclosed with a top," sealed and filled in [22]. Because of constant electrical wire leakages due to insulation failures, the eight miles of subways were dug up again and again before the right insulating system was finally hit upon in the autumn: "a compound that involved several layers muslin and then 'parafine, tar, Linseed oil and Asphaltum' [so that] the wires remained sound when the rain came" [23].

During the drawn-out digging-and-line-repair months of 1880, Edison designed a parallel circuit to replace the one-wire series circuit used by arc-lamp systems, a circuit with only one path for the current to flow, and thus not very practical for system that involved hundreds of separated lights. The parallel circuit involved a design that allowed the current to divide and follow multiple pathways simultaneously. It employed separate wires or "feeders" that led directly from the central station's "primary circuit" to run into each building in the system along a parallel "secondary" circuit. Edison's new primary circuit permitted electricity to flow through different branches, so lights on one branch could be turned off without affecting lights on the other branches.

This new "network of much thinner multiple 'feeder' copper wires coming from the central station," replaced the thick and expensive copper trunk wire, and was intersected "with many small mains that lit large clusters of lights" within each building [24]. Each customer had their own parallel circuit or main, with feeders off it to every outlet. Edison thus drastically reduced the bulk of his copper costs, the most expensive component of his system.

Meantime, early in 1880, another inventor had claimed the patent for the carbonized cardboard Edison had used as a filament in his Menlo Park public demonstration, forcing Edison's team to reevaluate and resume their search for a better filament. Apart from the fact that the carbonized fibers burned out after 300 or so hours – too few for commercial use – Edison knew that paper or cardboard was not going to prove satisfactory. "*Under the microscope it appears like a lot of sticks thrown together. There are places where the fibres are packed and other places where there are few fibres, dense spots and great open holes.*" Edison charged his top assistants to search the world's botanical literature (stored right in the Menlo Park library), and then hit the road, saying, *"Now I believe that somewhere in God Almighty's workshop there is a vegetable growth with* *geometrically parallel fibers suitable to our use. Look for it. Paper is man made and not good for filaments"* [25].

Unlike his competitors, Edison had ample funds and was able to pay his researchers to travel extensively, "one to Cuba, another to Brazil, a third to China and other points east." By mid-summer "in south-central Japan, they came across the Madake bamboo" [26]. The light bulb team experimented with bamboo fibers, along with bast fibers, for several months, until bamboo was shown to incandesce for over a thousand hours. From December on bamboo became the filament used in all Edison bulbs, until the inventor retired from the electricity business in 1892.

By late September, Edison converted his electric pen factory, located in an old Menlo Park barn, to produce "experimental runs of bulbs" needed for his second Christmas season light display, and put his chief scientist, Francis Upton, in charge of the factory. All components of the system were constantly tested and retested. "*Everything is so new that each step is in the dark,*" Edison confessed [27] After workmen finished laying newly insulated wires in the eight miles of trenches for the fourth time, "the first Menlo Park streetlights began to glow" in early November. "Soon Edison's and Upton's houses were connected to the central station, as were the miles of lights running up the hamlet's central plank road and then far out into the golden autumn fields" [28].

Numerous other, practical problems also had to be solved. For instance, how would the bulbs be fitted into sockets, affixed in old gaslight fixtures, and function as lamps? The team "came up with an original way of modifying the screw stoppers of kerosene cans (whence our screw-top bulbs today). They attached the vacuum bulbs so tightly to the screw [base] that no air would seep in and make the glowing filament burn too fast" [29]. The bulbs could then be easily screwed into sockets installed in converted gas lamp fixtures and turned on and off with a thumb screw (see Fig. 3).

In December 1880, Edison knew the "moment was drawing near to conquer the Empire City," and he and his investors also "knew the company needed to secure City Hall's permission to dig up Manhattan's streets." Edison's well-connected attorney arranged for the city aldermen to pay a visit to Menlo Park (on the same evening Charles Brush lit up Broadway with his arc lamps, creating the nation's first and most famous "Great White Way"). Edison showed the gentlemen from Tammany Hall the new bamboo-filament light bulb that "should last six months with normal use," he announced, and then, "with one turn of a wheel," Edison lit up "290 outdoor lights," setting them "aglow in the snowy streets and nearby pastures” outside the lab, turning them off with another turn of the wheel. “For men who knew only gaslights that required individual lighting and snuffing, this was something astonishing.” The display was followed by a banquet, where the “city’s superintendent of gas, no less, toasted Edison on his success. *“Gas,* said the superintendent, *is dangerous. It is very easy for a man to go to his hotel, blow out the gas and wake up dead … There is no danger of a man blowing out the electric light”* [30].

The electric light was on its conquering way.

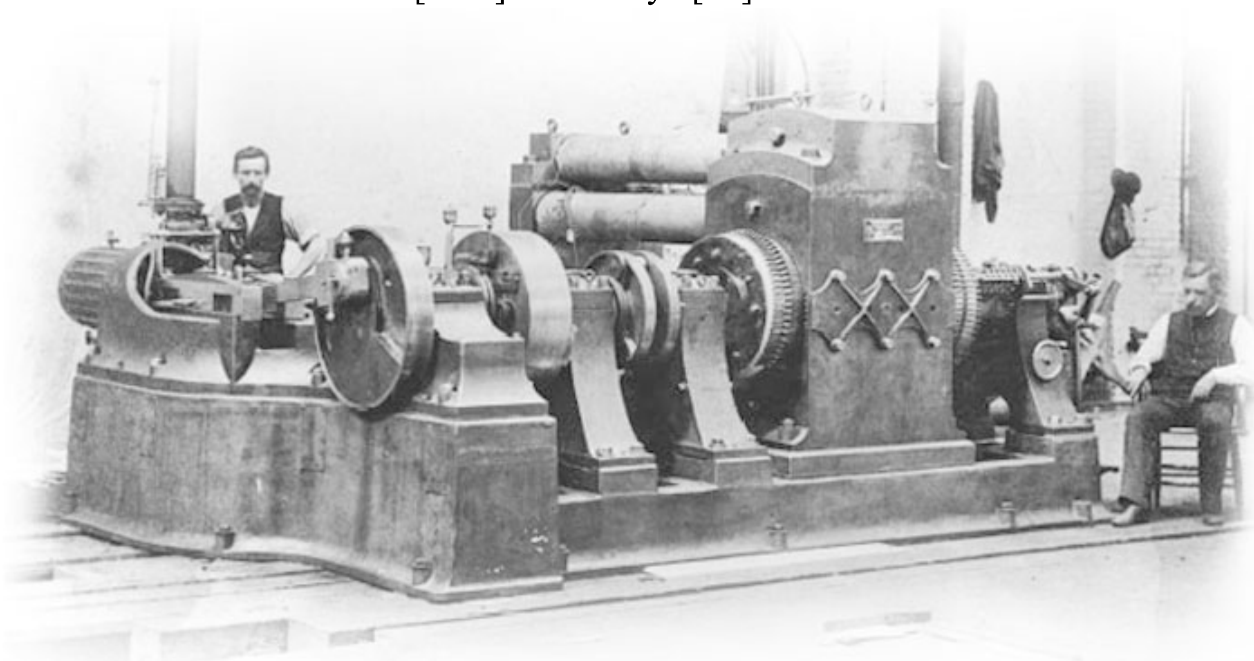
In February 1881 Edison moved his operations from Menlo Park to 65 Fifth Avenue in New York City to begin building his full-scale electric grid: it would be comprised of a large central station with coal-fired boilers that made the steam to power the engines to turn the shafts of multiple dynamos from which wires would run along miles of buried conduits into hundreds of homes and offices to light up thousands of lamps in lower Manhattan. In January, the company successfully installed a stand-alone system for a printing and lithography company on Water Street, located in what was to become Edison’s “first district” in lower Manhattan. Stand-alone factory systems would continue to develop, at far less cost, alongside central-station or electric grid systems, or utilities.

Although the directors of the Edison Electric Light Company supported the company’s stand-alone systems, they “*would not go into manufacturing*,” Edison much later recalled. To make all the components of his revolutionary grid, he was “*forced to the wall … forced to go into manufacturing myself … The issue is factories or death!*” [31]. Using his own money, Edison set up several companies, one to make dynamos, another to produce conduit (copper-wire-filled iron pipe), a third for voltage regulators, fuses, and fixtures, with a fourth already established in Menlo Park to make light bulbs.

In April, Tammany Hall finally gave the green light to begin construction of the “subways” or underground trenches in Edison’s proposed “first district” lighting system, which encompassed New York’s financial district as well as “Newspaper Row,” site of most of the city’s powerful newspapers. The digging of 18 stubborn miles of cobblestone streets began. Unbeknown to Edison and his coworkers, it would take almost a year and a half to complete. Though his financial backers grumbled at the extra cost the digging entailed, Edison believed “running wires overhead on poles might be dangerous,” and would “put electric power in competition with the dozens of telephone and telegraph wires already darkening the New York skies” [32]. The chaotic skeins of high-voltage arc-lamp wires being daily added to light the city’s streets, squares, theaters, large stores, and parks added to the problem of hazard. “Edison wanted nothing to do with these mangled nests of live and abandoned wires and insisted that the Edison system, by burying its wires, would be both safe and reliable” [33].

His decision pioneered the future of electric wiring in urban cores: by century’s end it was all underground, including both telephone and telegraph wiring.

Work was well underway on what later came to be called the “Jumbo” dynamo, nicknamed after P T Barnum’s famous circus elephant. Adapted from an earlier Werner von Siemens dynamo design, the new dynamo was four times larger than its largest competitor. “To reduce the energy lost in the linkage between generator and engine, Edison proposed to couple a large 100-horsepower generator with a steam engine rather than run several smaller dynamos with belts and pulleys.” Edison and one of his mechanical engineers developed “a special high-speed engine” pioneered by steam engineer manufacturer Charles T Porter [34]. Weighing 27 tons, Jumbo had a 10-foot armature shaft coupled to its Porter steam engine, giving it a 100-kilowatt output. “Direct coupling of the two elements,” the steam engine and the dynamo, with their “high-rotative speed” reduced their “overall size and increased [their] efficiency” [35].



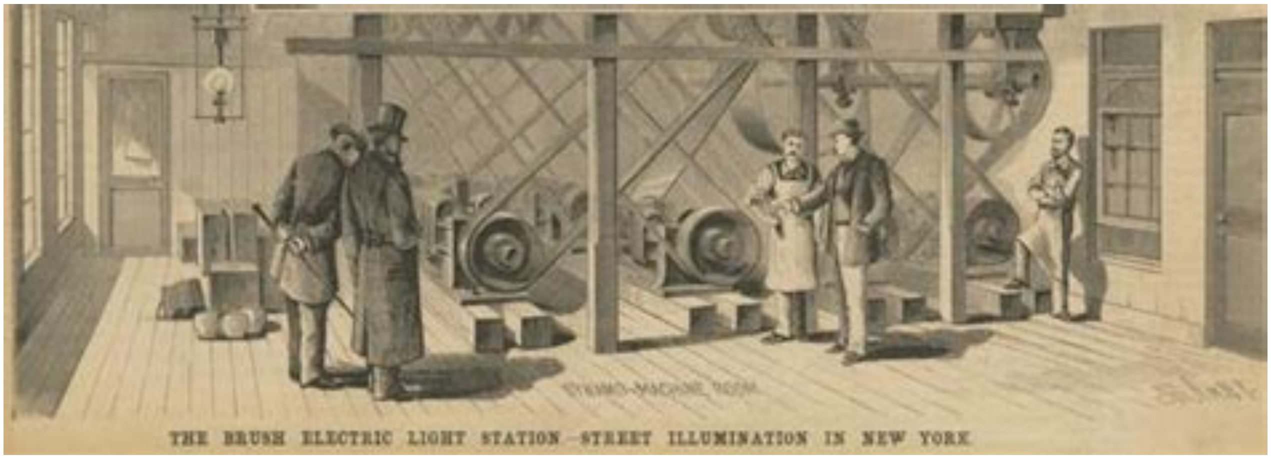


Figure 4. Top image shows Edison's 27-ton, constant-voltage Jumbo dynamo with a 10-foot armature shaft. Adapted from a Werner von Siemens design, it had a 100 kilowatt capacity and could supply 1,200 lamps. Edison coupled his powerful new dynamo to a nearby large Porter steam engine to reduce energy loss. The new setup did away with running several smaller dynamos with belts and pulleys, as shown by the drawing of Charles Brush's West 25th Street central station in Manhattan, launched to illuminate Broadway in December 1880, which became known as America's first "Great White Way." SOURCES: (top) https://www.asme.org/about-asme/engineering-history/landmarks/48-edison-jumbo-engine-driver-dynamo
(bottom)
https://en.wikipedia.org/wiki/File:Brush_central_power_station_dynamos_New_York_1881.jpg.

By spring, Edison dispatched one of his principal assistants, Charles Batchelor, to Paris to set up a European branch of the Edison Electric Light Company, and another trusted colleague, Edward Johnson, to establish an English subsidiary, as well as a central-station project near London's Holborn Viaduct to serve as a pilot test for the New York central station. The English company was to license and build central power stations as well as "isolated" or stand-alone plants for factories and buildings in England. Batchelor was to do the same on the continent and was meantime also responsible planning and setting up the large Edison exhibit for the world's first International Electricity Exposition in Paris, a major logistical assignment.

The Paris exposition opened in mid-August 1881 and ran through mid-November. Billed as "the first open and equal competition between rival electrical systems," it drew inventors from both sides of the Atlantic. Edison arrived well prepared for this “showdown.” Foremost of his many competitors was Joseph Swan, who had been installing light bulbs in homes and landmarks in England ever since he obtained a British patent for his “parchmentized thread” electric bulb in November 1880. Twenty years older than Edison, Swan had been researching incandescent light off-and-on since 1848. After obtaining a Spengler vacuum pump in the mid-1870s he renewed his research and gave a series of public lectures from December 1878 through February 1879 demonstrating his incandescent bulbs. By December 1879, having earlier installed a complete incandescent lighting system for his own house, he installed one for a wealthy friend and patron, providing the world’s first examples of full residential lighting by incandescent bulbs. Before that, in February 1879, Swan had “set out the world’s first incandescent streetlamp in front of his shop, drawing several thousand curious spectators.” A local newspaper reported: “*For hours the crowds stood and gazed ... people were evidently most reluctant to leave*” [36].

When Swan visited Paris for the 1881 exposition, he was awarded the Légion d’honneur, France’s highest decoration, and he got to see many of the city’s streets lit by his own incandescent lamps. But it was Edison who won the only Gold Medal for electricity in 1881. The Paris exposition “served as a most visible place for an excited public to see for themselves how well the incandescent light could deliver on its brilliant promises ... Edison’s display dwarfed all others … powered by the largest dynamo ever made, the ‘great machine from America’ ... both larger and far more efficient than anyone else had thought possible” [37]. At the Paris fair, Edison also boldly “unveiled blueprints for the world’s first central generating station, which he announced he would construct in two warehouses on Pearl Street in lower Manhattan” [38].

On both sides of the Atlantic, many experts and journalists had publicly doubted the “Boy Wizard” of Menlo Park would be able to make good his promise to deliver a functional incandescent lighting system capable of serving multiple businesses and residences from one single source. He had earlier boasted his new system would debut in May 1881, but the actual debut, even by the time of the Paris exposition, was still a long way off. Nonetheless, in Paris Edison demonstrated “a complete lighting system that linked his powerful and more efficient dynamo through a central main, feeders, and switches, to an incandescent bulb of superior design. His system delivered a steady supply of current to hundreds of lights, at varying distances from the source of power, and used parallel circuits to maintain the current even when some of his lights burned out or were turned off.” His unique high-resistance filament permitted him to use a low-voltage current that was much safer than arc-lamp current. “Other inventors in Paris,” such as Joseph Swan, “had shown that they could light a house; Edison was well on his way to lighting an entire city neighborhood” [39].

Although Swan himself “believed that he had anticipated Edison in regard to the carbon lamp,” he nonetheless understood that Edison “*has seen further into this subject,* [more] *vastly than I, and foreseen and provided for details I did not comprehend until I saw his system,*” at the Paris exposition [40].

Edison had purchased two adjacent four-story buildings on Pearl Street in lower Manhattan in August, prior to visiting the Paris exposition. He “carefully chose the service area and location for his first full-scale central station after conducting extensive market research. He wanted a densely populated area having a mix of commercial and residential uses. He also well understood the value of newspaper publicity and the need to impress and interest his present and potential financial backers.” Edison’s First District comprised but “a tiny portion” of Manhattan, as shown in Figure 7. Though tiny, the First District carefully circumscribed the heart of Manhattan’s “high-profile downtown business district, the financial capital of the United States,” and “also home to the city’s influential newspapers” [41].

Figure 5. Left side, drawing of the two adjacent warehouses on Pearl Street that Edison purchased in August 1881 to install his pioneering central station. On right, a map of lower Manhattan that shows Edison's First District encircled.
SOURCE:
https://ethw.org/File:Pearl3.jpg https://ethw.org/File:Pearl1.jpg

The hand digging of 18 miles of subways took far more time than Edison and his team expected. It was mostly done "at night when the city's much maligned street-cleaning crews spread out to remove two to three million pounds of equine manure left behind each day by the city's 150,000 horses" [42]. Edison and his foreman had to install junction boxes located every twenty feet in the slowly excavated grid of trenches. "The air was usually fouled with smoke from the plethora of coal-fired steam engines that were providing power to factories, print shops, and other industries" [43]. To exacerbate matters, during the summer the supply of copper wiring and iron pipes had come to a halt. Soon after the Paris exposition ended, snow and freezing ground brought the digging to a standstill. By December, the press was grumbling about Edison's broken promise of electric light for the First District by November 1881.

Figure 6. Illustration is from the June 21, 1882, *Harper's Weekly*, and is titled "The Electric Light In Houses: Laying The Tubes For Wires In The Streets Of New York."
SOURCE:
http://www.hevac-heritage.org/built_environment/pioneers_revisited/surnames_a-o/edison.pdf

Progress was being made elsewhere meantime. In London that December, the just-opened Savoy Theater, built to showcase Gilbert and Sullivan's comic operettas, installed a Siemens dynamo on open ground nearby and wired it to over a thousand of Swan's electric bulbs inside the theater. With the addition of a second dynamo on December 28, the Savoy became "'the first public building in the world to be permanently lit in all areas by electric [incandescent] light and the first theatre to plunge the auditorium into darkness during the performance'" [44]. The following day, *The Times* announced and extolled the superiority of electric over gas light.

Two weeks later, Edward Johnson, manager of Edison's London-based Electric Light Company, arranged to bypass the gas companies' control of London's streets by installing wires under the Holborn Viaduct, setting up the world's first public power station for incandescent lighting, the Edison Electric Light Station, which supplied light to neighborhood streets and private residences. A Jumbo dynamo, driven by a 125-horsepower steam engine, supplied a steady flow of 110-volt-DC current to customers. Using culverts, the British Edison company improvised a prototype grid to power nearly a thousand bulbs, a number that soon tripled. Edison and his associates used the Holborn Viaduct as a test case to prove the technical feasibility of Edison's Pearl Street central station concept, while avoiding the cost of digging subways.

Stand-alone or "isolated" dynamos, meantime, had serviced factories on both sides of the Atlantic for a decade, at least since Gramme and Fontaine had started their business selling dynamos in Paris. "By 1881, Edison's company was manufacturing complete systems consisting of a dynamo, wiring, switches, sockets and lamps … to light factories, large department stores" and other commercial venues. A year later, "more than 150 of these plants had been sold, powering more than 30,000 incandescent lamps" in the US [45]. By the time Charles Batchelder returned from Paris to New York during the spring of 1883, he had "overseen the installation of more than a hundred isolated plants all over Europe, in textile mills, factories, hotels, theaters, stores, steamships, shipyards, and railway stations" [46].

The Paris exposition stirred demand for the domestic use of the miraculous incandescent bulb. After Paris, "'if you had the money to get one area of your house electrified, that's what you did … You bought a generator system, and somebody came out and wired it for you and installed an electric light fixture somewhere in your home'." Among the very rich "light bulbs were suddenly status symbols" [47]. In early 1882 Edison investor William Vanderbilt used a generator to light up his Fifth Avenue mansion. Edison recollected, "*The large picture-gallery lined with silk cloth interwoven with fine granular thread. In some manner the two wires had got crossed with this tinsel, which became red-hot, and the whole mass was soon afire,*" and though "*it died out immediately ... Mrs. Vanderbilt became hysterical*." When she learned the source of the mayhem was in the basement, Edison recounted, "*[w]e had to take the whole installation out... houses afterward went onto the New York Edison system*," meaning no more boilers and generators for private residences [48].

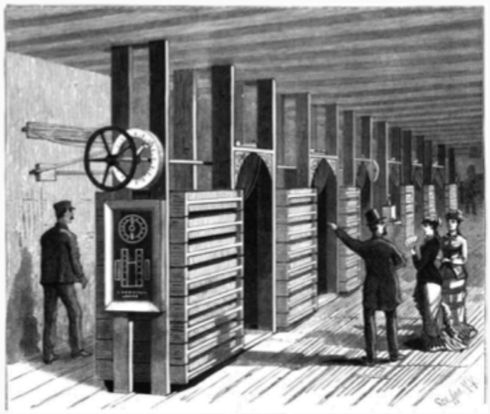
Another Edison investor, J P Morgan, was more indulgent. He also had his own private system installed, "including a light specially designed for his desk – the world's first desk lamp. When it was turned on for the first time, however, the lamp's faulty connections caused a fire that left the desk a charred ruin." But this did not dampen the great banker's enthusiasm for the incandescent light: he kept his lamps on and ignored his neighbors' complaints about the rumbling of his dynamo [49].

With the 1882 spring thaw, digging the half-completed system of subway trenches serving the First District resumed. In June Charles Brush acquired US rights to Joseph Swan's incandescent light to hedge his bets on his arc-lamp system and take advantage of the emerging demand for the new incandescent lighting.

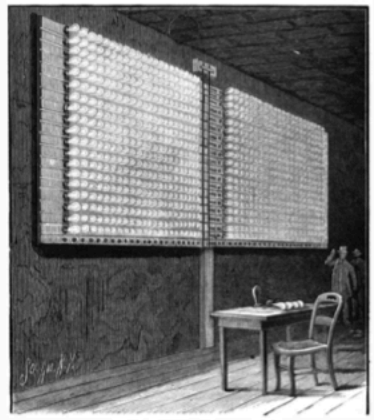
Edison insisted "electricity must be measured just like gas or water," even though it "could not be seen or weighed" [50]. Metering the electric usage of several residential and commercial users in one large system was terra incognita. That spring, the Edison team developed a workable electric meter for a multiple-user system, based on Edison's December 27, 1881, patent for a meter using electrolysis, or the electrochemical effect of current on a metal. The meter consisted of "a glass cell in which two plates of chemically pure zinc are dipped in a solution of zinc sulphate ... and a certain definite small portion of the current is diverted to flow through the meter, from the positive plate to the negative plate [so that] the latter increases in weight by receiving a deposit of metallic zinc," while the positive plate loses the same amount of metal. Each month the two plates were removed, washed, dried, and weighed in a "chemical balance" or special scale, while a new set of plates were inserted in the meter's glass cell to measure the following month's usage [51].

Though the Edison meter proved cumbersome to read and maintain, it was soon improved on by fellow electricians, most significantly by the inventor-industrialist Elihu Thomson, as well as by Edison himself. It sufficed meantime for the launch of the First District system, and it endured for many years afterward.

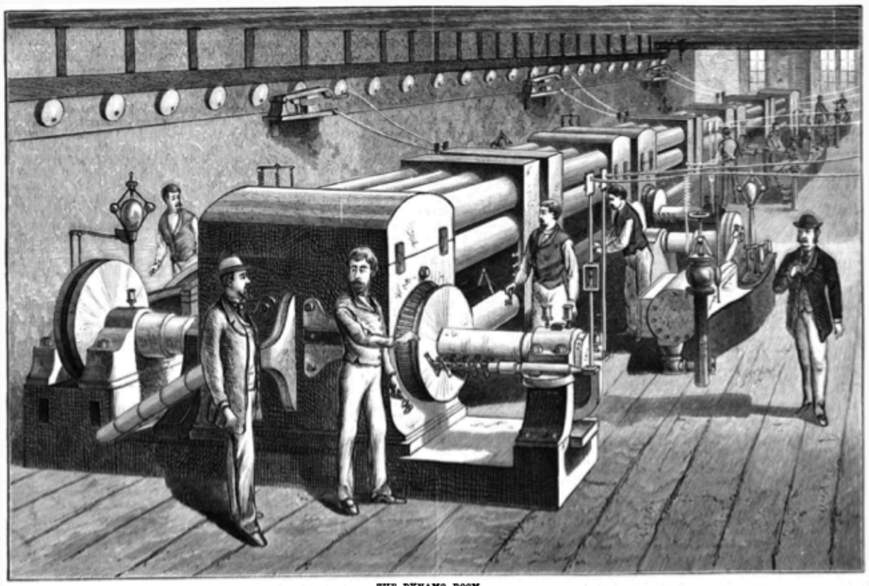
Of the two buildings on Pearl Street, one "was used for office, storage, and sleeping spaces," while the other, 257 Pearl Street, was slated to house the machinery of the central station. But it "was incapable of sustaining the weight of the engines and dynamos," planned for the floors above the basement. So "a floor of heavy girders supported by … 'pillars planted on heavy plates resting on three feet of solid concrete', not unlike the supporting structure of an elevated railroad," was built. Four "240-horsepower Babcock & Wilcox boilers occupied the basement ... Above them on the new iron frame rested the six [steam] engine and dynamo assemblies, each unit weighing about thirty tons and rated for 1,200 lamps." On the third floor, "copper wire resistances wound on large wooden frames were used for manual regulation of the dynamo fields," or voltages, while separate mechanisms were used "to manage the voltage on individual feeders." On the fourth and top floor "a battery of 1,000 lamps was used to test dynamos removed from the main circuit for inspection or repair" [52]. Coal was delivered and ashes removed and stored in a vault under the sidewalk, in the front of the building.



THE REGULATOR.



TEST BATTERY OF 1 000 LAMPS.



THE DYNAMO ROOM.

FIRST EDISON ELECTRIC LIGHTING STATION IN NEW YORK.

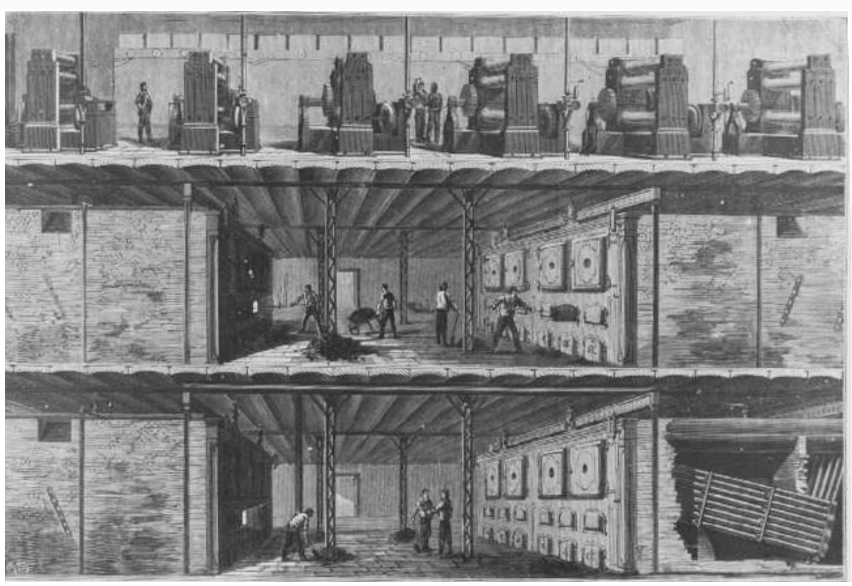


Figure 7. The world's first commercial central station, on 257 Pearl Street, New York: At bottom are four coal-fired steam boilers and directly above them, six steam engines; in the middle of the figure is the dynamo room with six Jumbo dynamos driven by the six steam engines. At the top, above the dynamo room, on the left are the voltage regulators, and to the right, the panel of 1,000-bulbs used to test dynamos needing repair or adjustment.
SOURCE:
https://ia801603.u.archive.org/19/items/scientific-american-1882-08-26/scientific-american-v47-n09-1882-08-26.pdf

In August Edison began "quietly testing" his nearly completed system, "running his generating and distribution system, hooking up various customers, and testing the lights" [53]. No one could be fully certain the electricity would be reliably contained in its wires and conduits, unable to escape to shock the unwary, especially the city's huge horse population. Along the eighteen miles of buried conduits, dotted with iron manhole covers "problems developed," most notoriously during the testing of the conduits themselves. "Stray currents from the failure of the insulation leaked to the street and reached the horses when their iron shoes came into contact with the metal utility manholes" and sent them wildly dancing [54].

On the afternoon of September 4, Edison and a few of his close associates walked into J P Morgan's office, where the banker and some fellow Edison Electric directors waited. At 3 PM Edison's chief engineer, John Lieb, "stood on his tiptoes and threw the main circuit breaker" at 257 Pearl Street while Edison simultaneously "closed the switch next to him" in JP Morgan's office. "'They're on!' cried the directors" [55]. And "*in a twinkling*," the 51-block area "*bounded by Spruce, Wall, Nassau and Pearl Street was in a glow* the *New York Herald* reported the next day. "The electricity utility had arrived" [56].

"Just as Edison had predicted, his customers loved his bulb at first sight." The bulb was all by itself a complex assembly with over two-dozen parts, yet it was merely the outward, visible result of a much more intricate system, "one of the most sophisticated pieces of technology yet created," a single immense machine. Crucially, "all the complexity had been engineered out of sight, invisible to the consumer." As a new customer explained, each light "'contains a key [thumb screw] whereby the lamp may be turned on or off at pleasure'." Safe and, in Edison's own words, "damned fool proof," it "was simple enough for all to use." The electric light "represented the culmination of decades of scientific insight, inventive genius, and technical skill" and "required no maintenance," while "the source of its power hummed out of sight" [57].

The light bulb contained all the magic of a mass-produced object, and the individual's possession and use of it conveyed little-to-no responsibility. It could be thrown away when broken or used up and a new one bought. It was, in a sense, free, and joyously modern.

Despite its triumphant debut in September 1882, Edison's direct-current electric grid, the world's first commercial grid, faced many challenges, both technical and economic, before the technology itself could become a world-spanning technological system. These challenges are the subject of Part 3.

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