Tangential Histories: Tungsten

A Material Exploration of Tunsten's Tangential Histories Including Incandescent Lighting, Mining, Industry, and the Modern Skyscraper

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INTRODUCTION

In the sequence of Modern American Architecture's narrative, several materials enter with rapid innovation and application. Water, glass, and steel were each applied, evolved, challenged, and explored resulting in high-rise towers, sheet-glass facades that glowed at night, deep floor plates that could be illuminated artificially, and fountains which moved alongside curated electric currents. There is one more material, however, working in partnership with each of these in order to achieve the two truly modern architectural characteristics of metallic strength and artificial illumination: Tungsten. Up until 1783, Tungsten had been only a mineral ore frequently found in mines of northern Europe with scheelite and tin; it was informally known as "Wolfram" for its wolf-like characteristics as a devourer of tin in refining processes. In fact, it was frequently considered waste and cast aside in favor of tin and scheelite. Within 130 years, however, the process of distilling and applying pure tungsten, adding it to recipes of steel, and stretching it into filaments would win it critical roles among other modern materials and events. Steel would get stronger, towers higher, and tunnels wider while workdays would get longer, industry would get faster, streets would get brighter, and rockets would travel further. In reference to its role in the first world war, some even called it "the new miracle metal… which could crack concrete and smash armor - or conversely blunt a shell" claiming that application of this precious metal "might just swing the outcome of a war."[1] In recognition of tungsten's invisible role in the shaping (or destruction) of modern architecture, this paper seeks to explore, specifically, tungsten's industrial relationship to incandescent light and steel.

***Figure 1** Tungsten mineral*[2]

1 BBC News. "World War One: Tungsten 'the Armour Plate of Conflict,'" June 6, 2014

2 "All About Tungsten, Including Its Use in Construction | Contractor Quotes," October 30, 2015.

HISTORY

Tungsten's extremely high melting point and strength as an alloy spurred innovations in steel and incandescent lighting in the late 19th and early 20th centuries. In the illustration produced in 1944, "40 Years: Growth of the Tungsten Tree,"[3] artist Wah Chang sought to document the incredible rapidity with which the modern world had adopted tungsten into burgeoning industries. The small thumbnail to the right in the image illustrates the use of tungsten as of 1904, when it was limited to the two chief focuses of this paper, electric lamp filament and high-speed steel. However, the larger tree illustrates four branches, where the steel forms the most significant branch. Importantly, these uses paved the way for a much wider field of applications including wear-resistant tools, dyes, water-proofing, fire-proofing, bullets and artillery, and fluorescent powders.

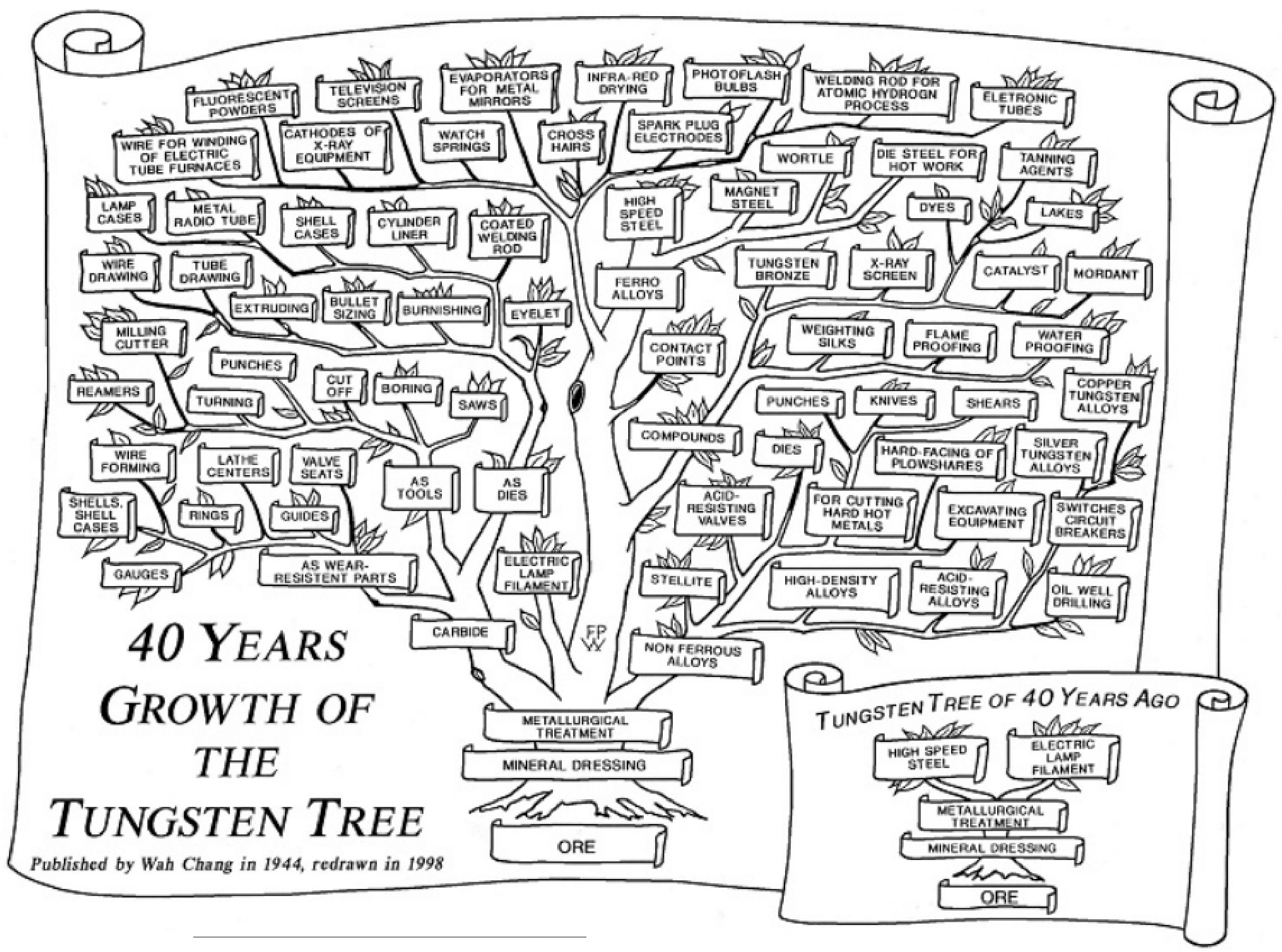

***Figure 2** "40 Years: Growth of the Tungsten Tree"*[3]

The process of mining and processing Tungsten begins with an ore that must be separated to extract the pure mineral. Because the tungsten makes up a fairly small percent of the overall material that is mined, mines generally require dressing plants within close proximity; this keeps transportation costs and energy expenditures lower.[4] The earliest tungsten mines were located in Germany and the Swedish province of Dalecarlia, and tungsten's name actually derived from the Swedish words tung (heavy) and sten (stone).[5] Because the stone is both heavy and naturally occurring as an ore, it can be difficult to transport and meticulous to refine. By the early twentieth century, tungsten mines could be found around the world, chiefly in Portugal, the US, England, Germany, Russia, and China. In 1917, a study from the University of Arizona Bureau of Mines identified 12 US states where tungsten ore was or could be found, while also documenting tungsten production around the world.

WORLD'S PRODUCTION OF TUNGSTEN

Metric Tons of Concentrates 60-65% WO

Mineral Resources 1913	1908	1909	1910	1911	1912
Argentina	497	817	1912	....	....
Australasia—					
New South Wales	244	325	321	398	232
Queensland	426	547	873	553	637
Tasmania	5	29	68	71	68
New Zealand	88	79	179	140	337
Austria	40	39	40	45	....
Bolivar	170	152	210	....	472
England	237	382	278	264	192
France	113	54	30	145	....
Germany	42	96	95	100	....
India	....	....	400	1329	....
Peru	....	....	12	12	....
Portugal	105	673	948	902	1228
Spain	226	129	153	96	....
United States	599	1469	1333	1172	1152

PRODUCTION AND VALUE IN UNITED STATES 1900 TO 1913

1900	46	$ 11,040	1907	1640	$890,046
1901	179	27,720	1908	671	229,958
1902	184	34,040	1909	1619	614,370
1903	292	43,639	1910	1821	832,992
1904	740	184,000	1911	1139	407,985
1905	803	268,676	1912	1330	502,158
1906	928	348,867	1913	1537	672,118

***Figure 3** World's Production of Tungsten 1917, Courtesy of the University of Arizona Bureau of Mines*[6]

3 Colwell, Brian D. "20 Interesting Facts About Tungsten," May 12, 2019.
4 "Tungsten Mining & Beneficiation | International Tungsten Industry Association (ITIA)." Accessed April 20, 2022.
5 "History of Tungsten | International Tungsten Industry Association (ITIA)." Accessed April 20, 2022.
6 Rubel, A. C. Tungsten: 1917-1918. University of Arizona, 1917.

Lovering, T. S.   362
W face of Tungsten Vein, 100 ft. level, looking west; following track of schist; down-throw on the north. Colorado. 1930.

Figure 4 *Image of a vein of Tungsten found in a Colorado mine in 1930*[6]

INCANDESCENT LIGHT

Tungsten found significant early application as the preferred filament material for the incandescent bulb. Since 1906, modern incandescent light has depended on Tungsten filaments as the only material that can withstand the heat of electric current and emit strong light for an extended period of time. Tungsten's central role in the evolution of the incandescent lamp makes it, too, central in the course of modern human events and environments as cities, societies, and empires adapted and built upon historical habits dictated by light.

6 "Tungsten Vein Mine (36)."

7 https://www.mindat.org/gl/1879?page=2.

Figure 5 *View of the Altenberg tin–tungsten mining area, ca. 1934*[7]

Light has historically reigned supreme in human environments. The advent of incandescent light had been anticipated in various cultures and societies, framing a stage for its eventual applications. On its own, light had been the metric of exterior exposure, working hours, safety, and daily rhythm. In 1616, William Drummond, a Scottish poet, wrote "I curse the night, but doth from day me hide!"[8] Romantic poets had begun to discuss what we might call "pre-industrial light" as a force with the power to not only illuminate but to carve space. In Percy Shelley's 1816 poem "Mont Blanc," he refers to two characters in the second stanza: "thou... dark, deep Ravine" and "fast cloud-shadows and sunbeams: awful scene."[9] These characters of light and dark – dark mountains versus flames, lightning versus tempest, ethereal veiled waterfall versus the obscured image – volley back and forth emphasizing light's power to the point of a terror. Percy was enamored with this natural force, fearful yet beholding of this "unremitting interchange with the clear universe of things around" which seemed to him heavenly, unattainable, and wild. Little did he know that just 63 years later, Thomas Edison would improve upon the 40 years of brief and erroneous incandescent illumination experimentation by electrifying a carbon filament inside a glass vacuum and thus producing a steady, small light for over fourteen hours.

Incandescent light achieves illumination by sending an electric current through a resistive material. A significant by-product of this action is heat, which eliminates the potential of many materials, such as charcoal,

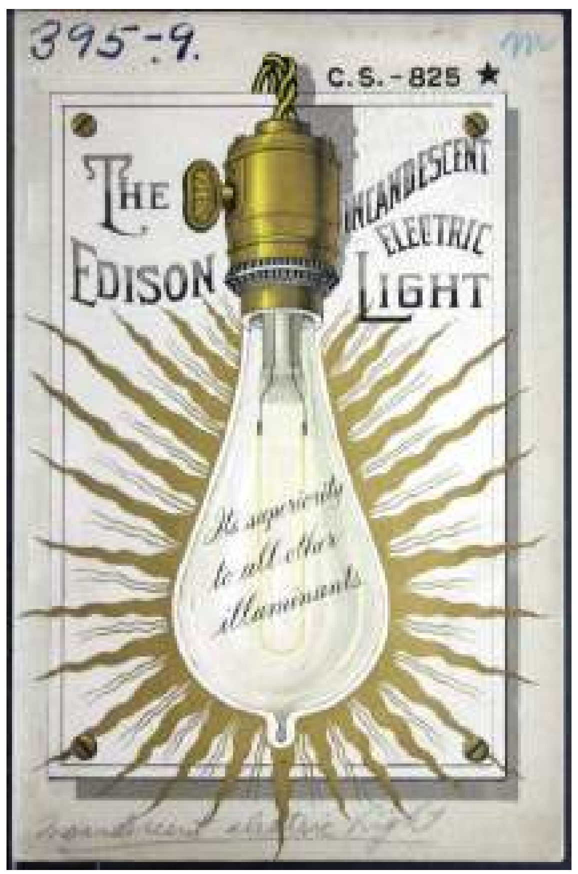

Figure 6 *The Edison incandescent electric light: "Its superiority to all other illuminants"*[10]

8 Drummond, William. "Sonnets, LIII." Accessed April 20, 2022. http://www.sonnets.org/drummond.htm.
9 Shelley, Percy. "Mont Blanc." The Poetry Foundation, 1816.
10 "Patent System Often Stifles the Innovation It Was Designed to Encourage."
11 National Museum of American History. "Model of Edison's Pearl Street Power Station."
12 "This Day in Lighting History: Sept. 4, 1882 | Architect Magazine."

bamboo, and even cotton, to act as viable conductors of the electricity as they would either melt or burn while emitting only a dull red light. Carbon, the material used in 1879 by Thomas Edison, has a melting point of 3500 C, thus allowing for up to forty hours of illumination. In 1882, the New York Times building at the Pearle Street station[11] became the first building ever to be illuminated by the electric incandescent bulb.[12] Over the course of many decades, other individuals would attempt the illumination by new materials and methods, including Willis Whitnew who added a metal coating to Edison's carbon filament, preventing the inside of the glass bulb from turning dark and thus allowing maximum light to pass through the vacuum envelope of the bulb. It was not until 1906 that General Electric

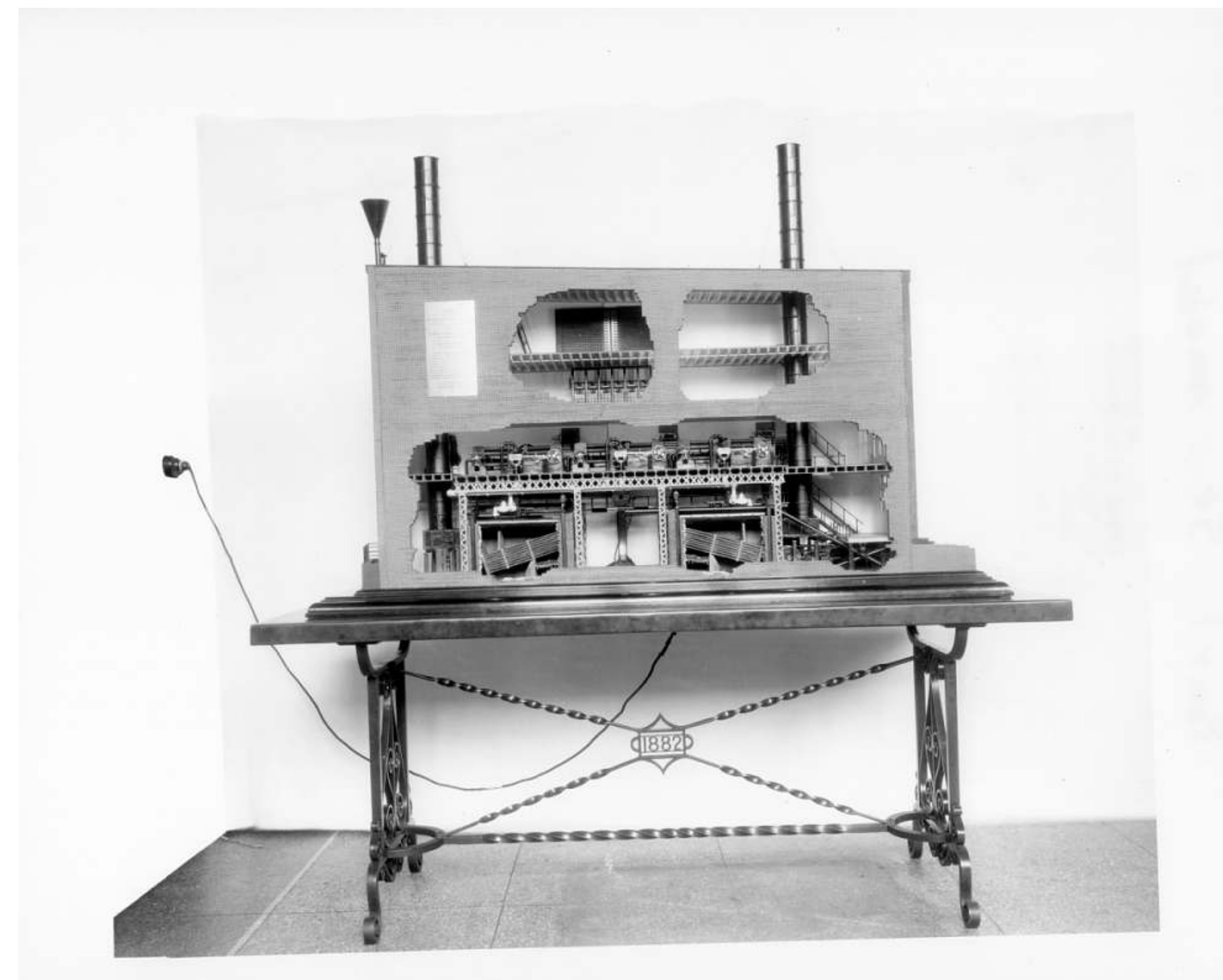

Figure 7 *Model of Thomas Edison's Pearle Street Station Used to Illuminate the New York Times Building in 1882*[11]

patented a method for making filaments out of tungsten – a material that proved to outlast all other filaments.[13] Here, tungsten becomes the focus of our light-driven story. At this moment in 1906, “light,” as humans knew it, transitioned away from its intrinsic relationships to heat, brevity, danger, chaos, and even fear to controlled, contained, constant, and safe. The length and lumens at which tungsten could burn inside a vacuum bulb effectively moved architecture from a type of cavern (in which Drummond may have hid) into a lantern.

The components of the incandescent bulb evolved rapidly from the period of 1835 to 1910. When William Coolidge invented an improved method for making tungsten filaments in 1910,[14] the costs of making the tungsten filament became more practical and made the incorporation of light bulbs across greater scales possible. Although tungsten’s role in the incandescent bulb is critical, it is only one part of a complex assembly of pieces and currents

Figure 8 *Illustrated 1919 ad depicting the tensile strength of tungsten filament used in Philips light bulbs*

which make an incandescent bulb work. In addition to the filament, there is also the thin glass which forms the exterior of the bulb known as the “globe,” an inert gas, a stem to hold the filament, and a metal base which screws into a fixed socket. Ultimately, tungsten truly was the perfect material to achieve prolonged incandescence. Not only can it resist extremely high temperatures and emit a strong light, but it also possesses a high tensile strength, as illustrated by the 1919 ad for the Philips bulb in Figure 8.

ENERGY

The widespread application of tungsten for prolonged emission of electric light is also entangled with the history (and environmental consequences) of energy generation and consumption. In March of 1891, Dr. C.F. Chandler spoke in a lecture to the Columbia School of Mines that “All the energy in the world...comes from sunshine.”[15] In light of electricity’s strengthening grip on urban environments, this moment recognized the sun, still, as the sole energy source by which an electric current was produced. The burning coal, taken from mines, had once been organic material nourished by the sun. Before delving into electricity’s energy relationships at the turn of the twentieth century, I’d like to give Dr. Chandler credit for his consideration of solar energy as far-preceding its direct conversion to energy through photo-voltaic panels. Still, it is a wonder if individuals of this time considered coal-energy as a “green” or “sustainable” energy source (according to present-day definitions of such terms) given its relationship to the sun.

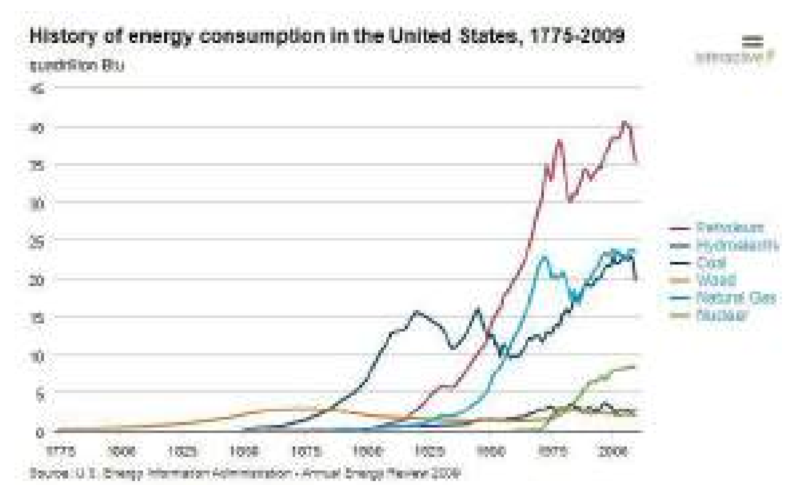

Figure 9 *History of Energy Consumption in the US shows highest dependency on coal in 1920 and 1945*[16]

13 “History of the Incandescent Light.” https://edisontechcenter.org/incandescent.html.

14 Bulb America. “The History of Incandescent Light Bulbs.”

15 “Life of Incandescent Lamps.” Scientific American. 2.

16 “History of Energy Consumption in the United States, 1775–2009.” https://www.eia.gov/todayinenergy/detail.php?id=10.

***Figure 10** De Volharding Building at Night*[18]

INCANDESCENT LIGHT APPLIED

The application of tungsten as an incandescent material had a strong and direct impact on architecture, urban environments, and human perception of natural versus curated energy environments. To fully invstigate the development of these relationships, we must travel back to mid-twentieth century: to the limits and by-products of power in the incandescent era. The incandescent lamp's dependence on electricity introduces a fraught relationship between light and the societal benefits associated with it and the by-products of electric-generation. As more city blocks, businesses, and residences experienced illumination, the dependence on coal as a fuel source for generating electricity also increased. The soot, smoke, and other pollutants unleashed into the atmosphere by burning coal acted as a direct

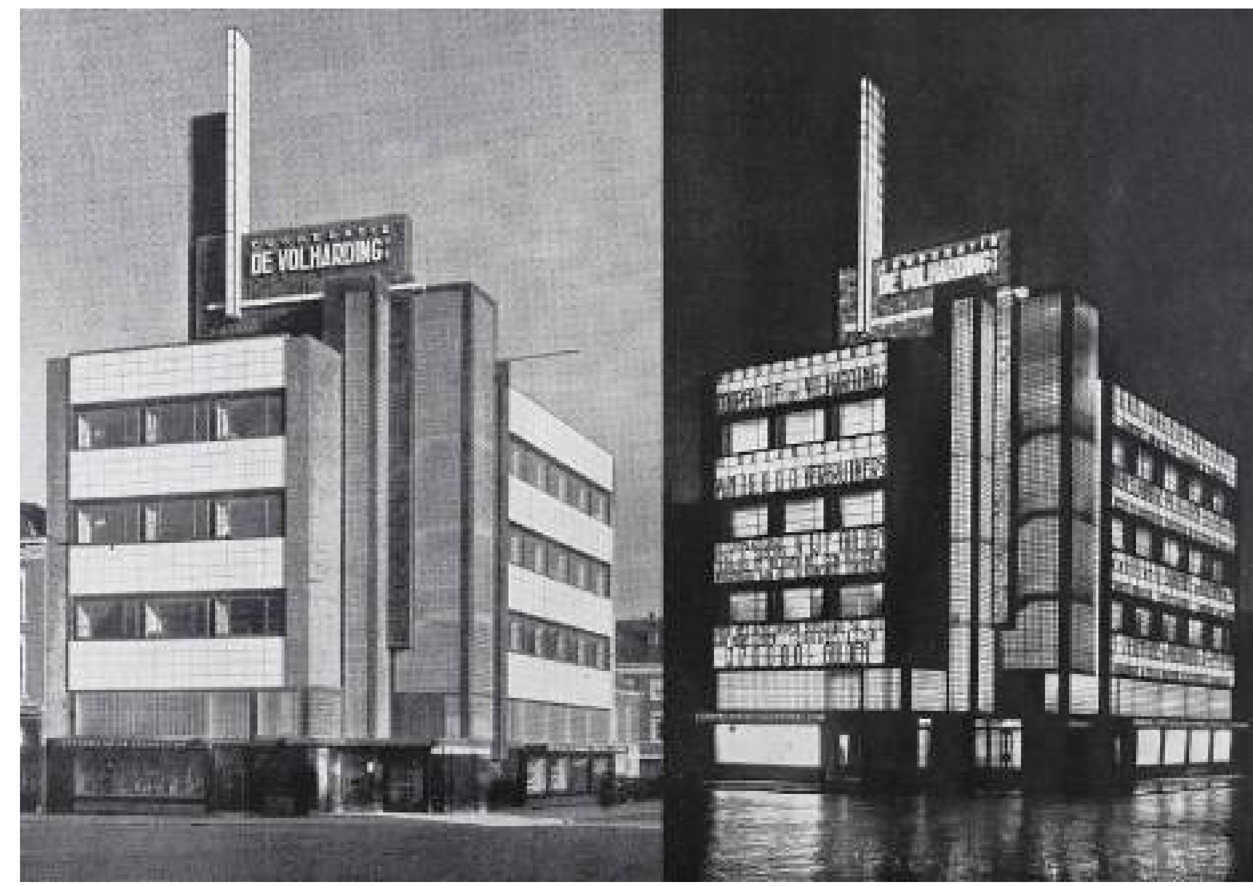

***Figure 11** De Volharding Building Day & Night*[19]

17 "Light Bulb Efficiency." Penn State Center for Nanoscale Science.
18 https://www.wikiwand.com/en/Architecture-of-the-night
19 Rehorst, Chris. "Jan Buijs and De Volharding, The Hague, Holland." Journal of the Society of Architectural Historians 44, no. 2 (May 1, 1985): 147–60.

antagonist to the artificial lighting movement. More light required more energy, which produced more soot, which darkened the skies, ultimately placing higher demands on incandescent lighting and energy sources. To make matters worse, the tungsten incandescent light emits only 10% of the total energy it demands as light. The other 90% of energy consumed by the product is lost as heat.[17] This is a direct consequence of using tungsten as filament because it can withstand such high temperatures. Only because tungsten is so heat resistant is it ideal for long-lasting and bright illumination. However, this same principle also makes it quite inefficient from an energy perspective - placing higher demands on energy production and exacerbating the adjacent issues of respiratory health, access to light, and cleanliness in urban centers.

Powered by burning coal, electrified-and glowing tungsten became a nighttime characteristic of architecture implying practical uses of safety and advertising. By the latter end of the 1920s, architects had adopted light as a design material both within the US and beyond. In 1927, Dutch architect Jan Buijs was commissioned to design the new headquarters for De

Figure 12 *The Chrysler Building joins New York's skyline amid the sky's dust and pollution.*[21]

Figure 13 *The Woolworth Building illuminating the night alongside streetlamps below*[22]

20 Rehorst, Chris. "Jan Buijs and De Volharding, The Hague, Holland." Journal of the Society of Architectural Historians 44, no. 2 (May 1, 1985): 147–60.

21 Limited, Alamy. "Skyline at Night with Public Library in Foreground and Chrysler Building in Background, New York City, USA, circa 1930's Stock Photo - Alamy."

22 Rehorst, Chris. "Jan Buijs and De Volharding, The Hague, Holland." Journal of the Society of Architectural Historians 44, no. 2 (May 1, 1985): 147–60.

Volharding in the Hague. De Volharding had requested the façade to be activated at night as a means of advertisements, and what resulted was "a whole structure" which, at night, "seemed transformed into a grand, luminous billboard, radiating its messages into the darkness."[20] This building takes on two distinct identities: one of stone, block, and strength in the daylight and the other of fine texture, invitation, and icon of the night (Figure 11).

Across the ocean, towers such as the Singer, Woolworth, and Chrysler Buildings were sprouting up in Manhattan. 1908's Singer Building was one of America's first skyscrapers to be lit at night, and the Woolworth, just five years later, was also floodlit at the top.[23] Designed by architect William Van Alen and completed in 1930, the Chrysler building's original drawings, reportedly, included plans to light the triangular crown elements projecting skyward on the tower's spire. However, it was not until 1981 that plans for the nighttime illumination of the seven-tiered crown were completed.[24] Never before could such nighttime radiance have been imagined as coming from within human's sheltering environments. The flood of light from within these skyward lanterns illuminated streets, tunnels, and skies. Figure 12, showing Midtown Manhattan, was taken around 1930 and shows how the towers lit the sky while the glass storefronts below lit the streets.


DIRT, DUST AND DIN KEPT OUT BY SOLID WALLS

Figure 14 Al Chase, "Chicago to Have World's First: Windowless Department Store." Chicago Daily Tribune. May 20, 1934. 26.[26]

Alternatively, armed with the ability to manufacture whole environments independent of natural light, (and to Drummond's earlier point) some architects withdrew from the exterior world entirely. In May 1934, The Chicago Daily Tribune announced that Sears would build the first "windowless department store."[25] In addition, the article reads that "it probably will be the first ever equipped mechanically at the time of its erection in such a way as to insulate its interior *from* its physical environment. Its air conditioning plant will control temperature, humidity, and air purification and movement."[27] Here, light seems to be intrinsically related to and inseparable from other environments, such as heat, dampness, and pollution and to keep one out means to keep them all out. The windowless Sears illustrates the designer's conflict with exterior environments; how to accept some, such as light, but guard from others, such as heat. The incandescent bulb's empowerment of the interior increased other dependencies on environmental manufacturing (that is, the curation of man-made interior environments) and thus catalyzed interest in more effective means of insulation, heating and cooling, and

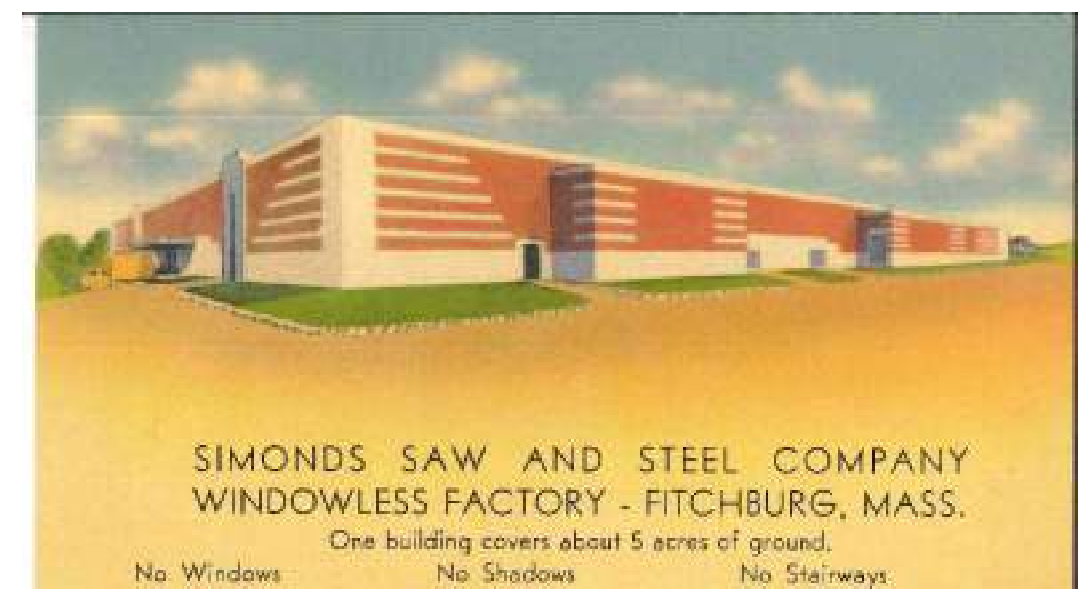

Figure 15 The Window-less Simonds Saw and Steel Company Building, 1931[29]

23 Nailuchen. "ARCHITECTURE OF THE NIGHT." On Technology and Architecture (blog), January 23, 2014.
24 Kernan, Michael. "The Night Light." Washington Post, September 17, 1981.
25 TWLESLIE. "Windowless Buildings." Architecturefarm (blog), July 21, 2010.
26 Leslie, Thomas, Saranya Panchaseelan, Shawn Barron, and Paolo Orlando. "Deep Space, Thin Walls: Environmental and Material Precursors to the Postwar Skyscraper." Journal of the Society of Architectural Historians 77, no. 1 (March 1, 2018): 77–96.
27 TWLESLIE. "Windowless Buildings." Architecturefarm (blog), July 21, 2010.
28 Leslie, Thomas, Saranya Panchaseelan, Shawn Barron, and Paolo Orlando. "Deep Space, Thin Walls"
29 Leslie, Thomas, Saranya Panchaseelan, Shawn Barron, and Paolo Orlando. "Deep Space, Thin Walls"

envelope treatments. Tungsten is thus joined in dialogue in modern human environments by other substances such as freon, asbestos, and fiberglass.

The Sears department store was not alone in its window-less philosophies. Also in the 1930s (31-37), the Simonds Saw and Steel Company of Fitchburg, Massachusetts constructed a factory entirely of solid walls. Instead of windows, the factory features "hundreds of 1,000

Figure 16 *Lever House Day & Night, 1952*

watt electric lights that provided more reliable and uniform lighting."[28] At the time, this was considered advanced design for its dependence on contemporary science in the creation of artificial lighting, ventilation, and other working conditions." In a more radical statement expressed as early as 1898, New York City architect and civil engineer Howard Constable projected that "an office building without windows, without air shaft, light well, or inner court, with each and every office lighted, heated, and ventilated artificially... [would have the] essential principle that the light and air required for offices can best be furnished by scientific appliances in the building itself rather than come from the outside world."[30] Although this may sound unpleasant to us sitting comfortably in our 21st-century seats as we set our sights on passive building systems, the bold and "with abandon" hopes for scientific environments, coupled with the capability of the incandescent bulb, placed control of interior environments, if they wanted it, entirely in the hands of the designer.

In the 1950s, modern design had returned to its prior fascination with transparency. Both the Seagram Building and Lever House demonstrated an attention to their nighttime identity, as both shift from tall dark masses in the day to a glowing network of filigreed glass and steel at night. At the Lever House, specifically, the artificial lighting from the interior partnered with the opaque exterior spandrel panels formed horizontal bands of illumination at night. In contrast to earlier buildings whose illuminated interiors looked merely like the same punched openings as the daytime, the floors of the Lever House seemed to release from one another, levitating in space in the darkness of the city sky beyond. A further innovation in towers, beyond nighttime advertising and window walls, included more expansive floor plates lit not only by the light of windows and light wells but from any interior distance from the building envelope. Though the Lever House still featured many small enclosed spaces in its floor plan, Naess & Murphy's Prudential Building, built in Chicago in 1955, had extraordinarily broad floor plates made possible by interior lighting, heating, and cooling systems[31]. Next to the Lever House's 11,000 ft^2 floor plates, the Prudential's 20,000 ft^2 each demonstrate a monumental expanse of floor system depth. In direct contrast to the window-less projects that were, by this time, twenty

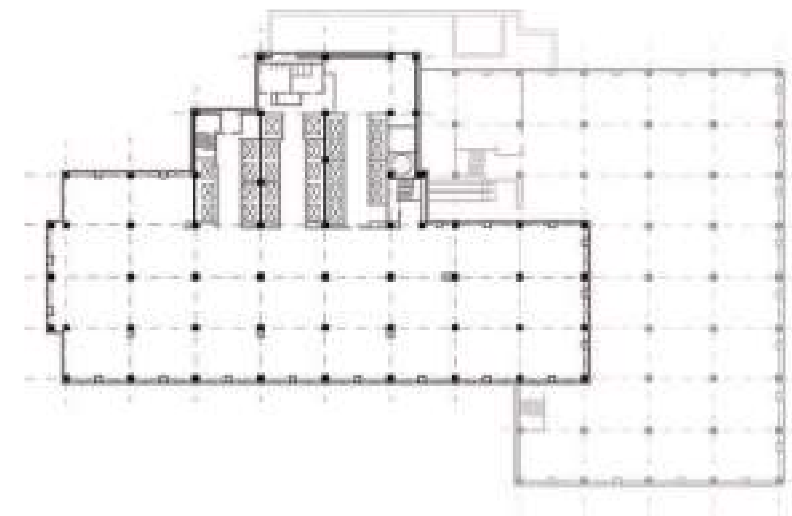

Figure 17 *Prudential Building (1955) Floorplate: 20,000 ft^2*[32]

Figure 18 *Subway construction in the light of incandescent bulbs*[33]

30 Howard Constable, quoted in "Windowless Buildings Next," Chicago Daily Tribune, 13 Mar 1898 ,37.
31 Leslie, Thomas, Saranya Panchaseelan, Shawn Barron, and Paolo Orlando. "Deep Space, Thin Walls"
32 Leslie, Thomas, Saranya Panchaseelan, Shawn Barron, and Paolo Orlando. "Deep Space, Thin Walls"
33 https://themindcircle.com/nyc-subway-construction/

years old, the Lever House and Prudential Building sought to marry the natural environment with the manufactured one. The hope was that both daylighting and artificial lighting (both incandescent and fluorescent) could create workable interior environments during the day, and that the enclosed box would radiate at night. ***Tungsten's role as an element of sustained incandescent ability was ultimately a symbol of environmental control.*** Where the city once dimmed along with the setting sun, it now buzzed with incandescent energies amid a grid of many, human-made glowing suns.

Furthermore, the application of electric light extended the work day, which was no longer limited to the fuel in a lamp or arc of the sun. It is worth noting that this element from the depths of the earth activated other industries: both in the dark and in the ground. The image in Figure 18 recounts the 1929 construction of the New York City subway system, lit by incandescent lamps receiving electricity from steam turbines installed for the sole purpose of lighting the tunnel-bound construction system.[34]

HIGH-SPEED STEEL

Parallel with innovations in artificial illumination were advances in the strength of steel. The early twentieth century saw Tungsten incorporated as an alloy to steel, solidifying its place as a precious commodity amid the oncoming industrial booms of the world wars. One chemist recounted the role of tungsten as "for most people... something used in those clever new light bulb things. Only Germany thought of it as a strategic metal."[35] With an atomic number of 74, tungsten is incredibly dense and, for this reason, became a precious asset, especially as an alloy in steel, for military operations and building practices into the twentieth century.

In general, tungsten has two applications in steel: it can come in the form of "high-speed steel," characterized by its hardness, wear and heat resistance. Alternatively, it can be considered tungsten steel, which simply refers to tungsten alloy in iron and is characterized by the high tensile strength and heat-resistance tungsten adds to the steel. Steel and tungsten, in a way, "grew up" together. In 1855, just as the Bessemer process for mass-producing steel was invented, the first tungsten-steels were produced in Austria.[36] By 1900, tungsten-steel, also known as high-speed steel, was exhibited at the World Exhibition in Paris.[37] At the turn of the century, the industrial and increasingly-global economies were quickly innovating and celebrating this new material. However, it wouldn't be until the first world war that tungsten

34 "Nycsubway.Org: The New York Subway: Chapter 07, Lighting System for Passenger Stations and Tunnel."
35 BBC News. "World War One: Tungsten 'the Armour Plate of Conflict,'" June 6, 2014, sec. England. https://www.bbc.com/news/uk-england-25596167.
36 Desjardins, Jeff. "The History of Tungsten, the Strongest Natural Metal on Earth." Visual Capitalist, May 1, 2017.

would become central to more than just incandescent lighting. Germany, when faced with a shortage of industrial diamonds in 1913, turned to alternate materials with the same strength as diamond. In K.C. Li's 1947 book, 'TUNGSTEN,' he writes that it was common belief among the Allies that Germany would be "exhausted of ammunition" within six months. When the opposite phenomenon took place, and Germany not only increased its manufacture of munitions but exceeded that of the Allies, it was due to the implementation of tungsten high-speed steel in cutting tools. Furthermore, and "to the bitter amazement of the British, the tungsten so used.. came largely from their Cornish Mines in Cornwall."[38] Thus, control of tungsten mines across the world, especially in the US and China, also came into sharper focus for their strategic use as industrial resources.

In the United States, tungsten mining became a significant component of the 1940s war effort and many domestic sources were unearthed and activated. In Idaho, significant reserves of tungsten were found in what became known as the Stibnite Mining District and, in a retrospective report from 1956, a member of the munitions board wrote that "the discovery of that tungsten at stibnite, Idaho, in 1942 shortened World War II by at least 1 year and saved the lives of a million American soldiers."[39] Today, the Stibnite Mining District is considered a historic district.

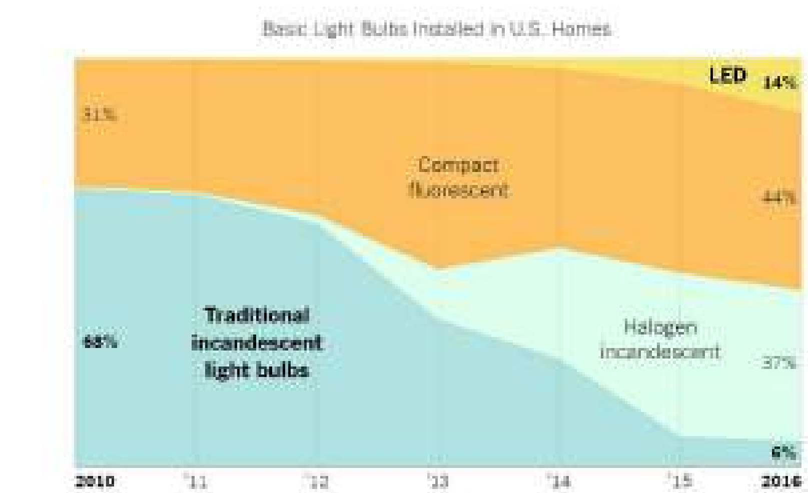

Figure 19 *"Basic Light Bulbs Installed in US Homes" 2010–2016*[42]

PRESENT-DAY TUNGSTEN

Despite its classification

37 Desjardins, Jeff. "The History of Tungsten, the Strongest Natural Metal on Earth." Visual Capitalist, May 1, 2017.
38 "History of Tungsten | International Tungsten Industry Association (ITIA)."
39 Perpetua Sources, "How the Stibnite Mining District Shortened WWII."
40 Desjardins, Jeff. "The History of Tungsten, the Strongest Natural Metal on Earth." Visual Capitalist, May 1, 2017.
41 "U.S. Army Unveils 'Green' Ammo." Greenbiz.
42 Popovich, Nadja. "America's Light Bulb Revolution." The New York Times, March 8, 2019.42

Figure 20 Stibnite Mining District, Idaho 1942[44]

as a rare metal, tungsten remains integral to modern human environments. Today, tungsten steel is widely used in the production of other hard metals as a cutting metal, as well as in wire filament, which today accounts for 5% of total tungsten production.[40] In the mid-1990s, the US Department of Defense recognized the environmental harm being caused by lead ammunition sitting for years and causing soil contamination in practice ranges.[41] Researchers began experimenting with tungsten ammunition, some even calling it "green" ammunition, for its naturally occurring properties and minimal contamination in processes of decay. Since then, the US Army has begun using tungsten rather than lead in most munition products.

As for the incandescent bulb, application of this type of lighting has dropped

Figure 21 *1932 General Electric advertisement for a more energy-efficient light bulb.*[43]

43 Popovich, Nadja. "America's Light Bulb Revolution." The New York Times, March 8, 2019.
44 Perpetua Sources, "How the Stibnite Mining District Shortened WWII."
43 https://www.ebay.com/itm/383509400191

significantly in the US due to shifting energy demands and alternative lighting options such as fluorescents and LEDs. In a New York Times article published in 2019, a graph illustrates the decline of dependence on incandescent bulb sin US households between 2010 and 2016, from representing 68% of all lighting consumption to a mere 6% in just 6 years.[42] As conversations around energy resiliency mature, alternative energy sources such as wind, solar, and hydro are reshaping America's energy economy. However, the simple shift in lighting technologies "has driven down electricity demand in American homes, saving consumers money and cutting greenhouse gas emissions."[44]

Today, tungsten is still significant among global industries and economies. According to data, "China is the leading supplier of tungsten, followed by Russia and Bolivia." Other countries that also produce tungsten are South Korea, Vietnam, Canada, Portugal, and Great Britain. At present, most tungsten reserves are held by China, Russia, and the US.[43] Tungsten's use as a steel alloy and incandescent filament not only shaped and illuminated modern American cities, but also played a critical role in defining events of the 19th and 20th centuries. It illuminated and strengthened cities, propelled construction underground and possibly swung the outcome of a war. In recognition of this vital yet limited resource, as architects, designers, and conservators, it is now our responsibility to not only understand the historical and economic histories of tungsten, but also how it might be recycled, reapplied, and re-ignited as a material that isn't outpaced by innovations in the energy sector. Thus, our question is this: How can tungsten's place among illuminated cities be preserved amid an ever-modernizing energy ecosystem?

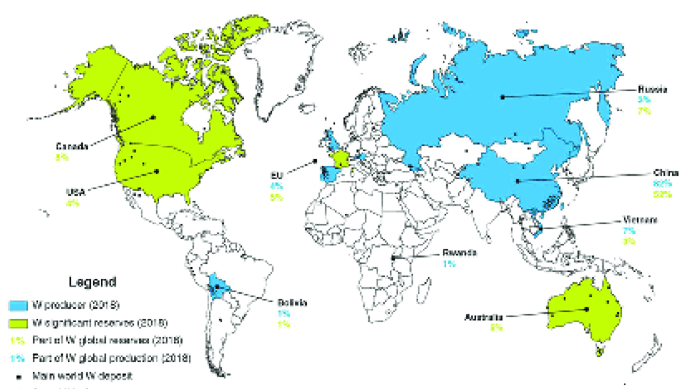

***Figure 21** Tungsten production worldwide, 2018 (W = Tungsten)*[46]

44 Popovich, Nadja. "America's Light Bulb Revolution." The New York Times, March 8, 2019.
45 https://investingnews.com/where-is-tungsten-mined/
46 Research Gate. "FIGURE 2 | World Map of Main W World Deposit, W Mines, W Producers And..."

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