The Invention of the Electric Light

B. J. G. van der Kooij

This case study is part of the research work in preparation for a doctorate-dissertation to be obtained from the University of Technology, Delft, The Netherlands (www.tudelft.nl). It is one of a series of case studies about "Innovation" under the title "*The Invention Series*".

About the text—This is a scholarly case study describing the historic developments that resulted in the steam engine. It is based on a large number of historic and contemporary sources. As we did not conduct any research into primary sources, we made use of the efforts of numerous others by citing them quite extensively to preserve the original character of their contributions. Where possible we identified the individual authors of the citations. As some are not identifiable, we identified the source of the text. Facts that are considered to be of a general character in the public domain are not cited.

About the pictures—Many of the pictures used in this case study were found at websites accessed through the Internet. Where possible they were traced to their origins, which, when found, were indicated as the source. As most are out of copyright, we feel that the fair use we make of the pictures to illustrate the scholarly case is not an infringement of copyright.

Cover art is a line drawing of Edison's incandescent lamp (US Patent № 223.898) and Jablochkoff's arc lamp (US Patent № 190.864) (courtesy USPTO).

Version 1.1 (April 2015)

ISBN-10: 1503185362
ISBN-13: 978-1503185364

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Preface

When everything is said and done,
and all our breath is gone.
The only thing that stays,
Is history, to guide our future ways.

My lifelong intellectual fascination with technical innovation within the context of society started in Delft, the Netherlands, in the 1970s at the University of Technology, at both the electrical engineering school and the business school.[1] Having been educated as a technical student with vacuum tubes, followed by transistors, I found the change and novelty caused by the new technology of microelectronics to be mind-boggling, not so much from a technical point of view but with all those opportunities for new products, new markets, and new organizations, with a potent technology as the driving force.

During my studies at both the School of Electric Engineering and the School of Business Administration,[2] I was lucky enough to spend some time in Japan and California, noticing how cultures influence the context for technology-induced change and what is considered novel. In Japan I explored the research environment; in Silicon Valley I saw the business environment—from the nuances of the human interaction of the Japanese, to the stimulating and raw capitalism of the United States. The technology forecast of my engineering thesis made the coming technology push a little clearer: the personal computer was on the horizon. The implementation of innovation in small and medium enterprises, the subject of my management thesis, left me with a lot of questions. Could something like a Digital Delta be created in the Netherlands?

[1] At the present time it is the Electrical Engineering School at the Delft University of Technology and the School of International Business Administration at the Erasmus University Rotterdam.
[2] The institutions' actual names were Afdeling Electro-techniek, Vakgroep Mikro-Electronica, and Interfaculteit Bedrijfskunde.

During the journey of my life, innovation has been the theme. For example, in the mid-1970s, I joined a mature electric company that manufactured electric motors, transformers, and switching equipment, and business development was one of my major responsibilities. How could we change an aging corporation by picking up new business opportunities? Japan and California were again on the agenda, but now from a business point of view. I explored acquisition, cooperation, and subcontracting. Could we create business activity in personal computers?

The answer was no.

I entered politics and became a member of the Dutch Parliament (a quite innovative move for an engineer), and innovation on the national level became my theme. How could we prepare a society by creating new firms and industries to meet the new challenges that were coming and that would threaten the existing industrial base? What innovation policies could be applied? In the early 1980s, my introduction of the first personal computer in Parliament caused me to be known as "Mr. Innovation" within the small world of my fellow parliamentarians. Could we, as politicians, change Dutch society by picking up the new opportunities technology was offering?

The answer was no.

The next phase on my journey brought me in touch with two extremes. A professorship in the Management of Innovation at the University of Technology in Eindhoven gave room for my scholarly interests. I was (part-time) looking at innovation at the macro level of science. The starting of a venture company making application software for personal computers satisfied my entrepreneurial obsession. Now it was about the (nearly full-time) implementation of innovation on the microscale of a start-up company. With both my head in the scientific clouds and my feet in the organizational mud, it was stretching my capabilities. At the end of the 1980s, I had to choose, and entrepreneurship won for the next eighteen years. Could I start and do something innovative with personal computers myself?

The answer was yes.

When I reached retirement in the 2010s and reflected on my past experiences and the changes in our world since those 1970s, I wondered what made all this happen. Technological innovation was the phenomenon that had fascinated me along my entire life journey. What is the thing we call "innovation"? In many phases of the journey of my life, I tried to formulate an answer: starting with my first book, *Micro-computers, Innovation in Electronics* (1977, technology level), next with my second book, *The*

Management of Innovation (1983, business level), and my third book, *Innovation, from Distress to Guts* (1988, society level). In the 2010s I had time on my hands. So I decided to pick up where I left off and start studying the subject of innovation again. As a guest of my alma mater, working on my dissertation, I tried to find an answer to the question "What is innovation?"

It started in Delft. And seen from an intellectual point of view, it will end in Delft.

B. J. G. van der Kooij

About the Invention Series

Our research into the phenomenon of innovation, focusing on technological innovation, covered quite a time span: from the late seventeenth century up to today. The case study of the steam engine marked the beginning of the series. That is not to say there was no technological innovation before that time. On the contrary, *imitation, invention*, and *innovation* have been with us for a much longer time. But we had to limit ourselves, as we wanted to look at those technological innovations that were the result of a "general purpose technology" (GPT). Clearly some clarification is needed here, so we will define the major elements of our research: innovation, technology, and GPT.

We define *innovation* as the creation of something new and applicable. It is a process over time that results in a new artifact, a new service, a new structure or method. Whereas invention is the discovery of a new phenomenon that does not need a practical implementation, innovation brings the initial idea to the marketplace, where it can be used. We follow Alois Schumpeter's definition "Innovation combines factors in a new way, or…it consists in carrying out New Combinations…" (Schumpeter, 1939, p. 84). Innovation is quite different from invention: "Although most innovations can be traced to some conquest in the realm of either theoretical or practical knowledge, there are many which cannot. Innovation is possible without anything we should identify as invention, and invention does not necessarily induce innovation, but produces of itself…no economically relevant effect at all" (Schumpeter, 1939, p. 80). What about invention then? We follow here Abott Usher's interpretation, where the creative act is the new combination of the "Act of skills" and the "Act of insight": "Invention finds its distinctive feature in the constructive assimilation of preexisting elements into new syntheses, new patterns, or new configurations of behavior" (Usher, 1929, p. 11).

We define *technology* as the knowhow (knowledge) and way (skill) of making things. Technology is more than the "technique" from which it originates. "Technology is a recent human achievement that flourished conceptually in the 18th century, when technique was not more seen as skilled handwork, but has turned as the object of systematic human knowledge and a new 'Weltanschaung' (at that time purely mechanistic)" (Devezas, 2005, p. 1145). We follow Anna Bergek and associates here: "The concept of technology incorporates (at least) two interrelated meanings. First, technology refers to material and immaterial objects—both hardware (e.g. products, tools and machines) and software (e.g. procedures/processes and digital protocols)—that can be used to solve real-world technical problems. Second, it refers to technical knowledge, either in general terms or in terms of knowledge embodied in the physical artifact" (Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008, p. 407).

We define a *general purpose technology* as the cluster of technologies of which the resulting innovations have considerable impact on society: "the pervasive technologies that occasionally transform a society's entire set of economic, social and political structures" (Lipsey, Carlaw, & Bekar, 2005, p. 3). It results in what we are identifying as the Industrial Revolution, the Information Revolution. It is the engine of economic growth, but also the engine of technical, social, and political change, the engine of creative destruction. We follow Richard Lipsey et al. when he defines: "a GPT is a technology that initially has much scope for improvement and eventually to be widely used, to have many uses and to have many spillover effects" (Ibid., p. 133). The GPT is not a single-moment phenomenon; it develops over time: "they often start off as something we would never call a GPT (e.g. Papin's steam engine) and develop in something that transforms an entire economy (e.g. Trevithick's high pressure steam engine)" (Ibid., p. 97).

The case studies are about observing phenomena as they occur in the real world—for example, the development of the steam engine, from which one can conclude it was a GPT according to the definition. The observation of what caused the Second Industrial Revolution is more complex. Is "electricity" the GPT, or is the electro-motor and the electric dynamo the GPT? Or can it be that the resulting development of the electric light and telegraph is a GPT on its own? The interpretation becomes more complex, the opinions diffused, especially when one looks at the present time, for example, at the phenomenon of the Internet.

About our research

This book is the fourth manuscript in the Invention Series, a series of books on inventions that created the world we live in today. In the first manuscript, *The Invention of the Steam Engine*, we explored a methodology to observe and investigate the complex phenomena of "technological innovation" as part of a general purpose technology (GPT). In that case, it was about the *steam technology* that fueled the Industrial Revolution. One could consider that case study as a trial if our methodology could be applied. It looked promising enough to try again. So let's describe the basic elements of our research.

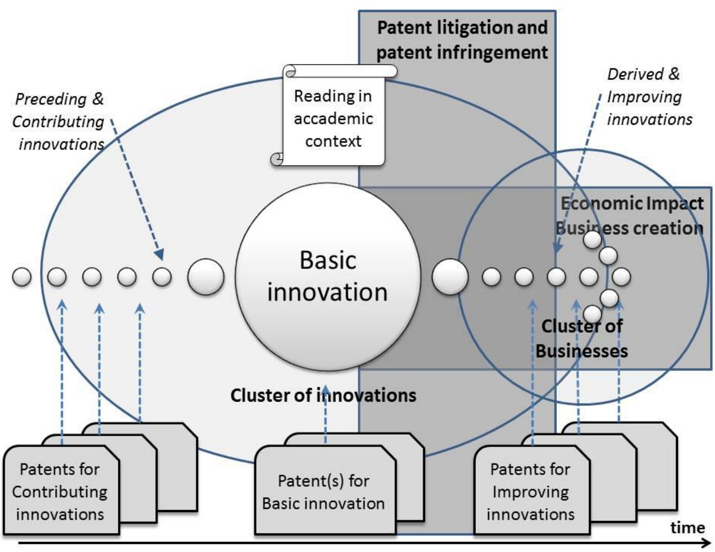
Now our *field of interest* is the GPT of electricity, in particular, the areas of application of the electric light. To understand what happened that this technology could light the next Industrial Revolution, we applied the method of the case study. The case-study method offers room for "context and content." The context is the "real-life context": the scientific, social, economic, and political environment in which the observed phenomena occurred. The content is the technical, economic, and human details of those phenomena. The reader will recognize this in the structure of the manuscript.

The case study is based on a specific *scholarly view* to observe the phenomena as they occurred in the real world. This view is based on the construct of "clusters of innovations" as identified by early twentieth-century scholars active in the Domain of Innovation Research. Among those economists was Alois Schumpeter, who related the clusters of innovations to business cycles under the influence of creative destruction: "because the new combinations are not, as one would expect according to general principles of probability, evenly distributed through time…but appear, if at all, discontinuously in groups or swarms" (Schumpeter & Opie, 1934, p. 223); "the business cycle is a direct consequence of the appearance of innovations" (Ibidem., pp. 227–230). For Schumpeter it was the entrepreneur that realized the innovation and, as imitators were soon following in the entrepreneurial act, thus created the business cycles that are nested within the economic waves. Later it was Gerhard Mensch and Jaap van Duijn who related the basic innovation within the clusters to the long waves in the economy with respect to industrial cycles. Mensch related the cyclic economic pattern to basic innovations: "The changing tides, the ebb and flow of the stream of basic innovations explain economic change, that is, the difference in growth and stagnation periods" (Mensch, 1979, p. 135). Duijn referred to innovation cycles (Duijn, 1983). More recently it was scholars like Dosi, Tushman, Anderson, and O'Reilly who developed, as part of their view on technological revolutions and technological trajectories, the construct of the dominant design. This Dominant Design we considered to be the basic innovation.

So our *unit of analysis* is the cluster around the basic innovation with the preceding and derived innovations. We choose for embedded multiple case design of the GPT "steam technology" (a collection of many mechanical, hydraulic, and related technologies explored in the first manuscript) and the GPT "electric technology" (idem, this manuscript). The method is *multiple*, as we looked simultaneously at the scientific, technical, economic, and human aspects. It is *embedded* because we looked simultaneously at the individuals (the inventors, the entrepreneurs), the organizations (their companies), and societies—thus making the analysis multilevel and multidimensional. Our qualitative data originate from general, autobiographic, and scholarly literature (see References), creating a mix of sources that are quoted extensively. Our quantitative data were sampled from primary sources like the United States Patent Office (USPTO).

Our *perspective* was the identification of patterns that are related to the cluster concept. Can clusters of innovation within a specific general purpose technology be identified? If so, how are they related, and how are the clusters put together? The first pilot case showed that it could be done. So in this case study, our objective was to identify the basic innovations that played a dominant role in the GPT of electricity that created the (second) Industrial Revolution. As we used *patents* as innovation identifiers, and used *patent wars* (patent infringement and patent litigation) and *economic booms* (business creation, business and industry cycles) to identify basic innovations, this aspect is quite dominant in the study.

In the scheme below, the "Cluster of Innovations" and the related "Cluster of Businesses" concept is visually represented.



Scheme 1: The construct of the Cluster of Innovations and Cluster of Businesses.

About this case study

This case study is the result of our quest in the Nature of Innovation. It is divided in the following sections:

Context for the discoveries: We will begin with a thorough look at the events that created the historical climate of the time. Although these events are not directly related to the invention of electric light itself, the social, economic and political turmoil—followed by relative peace—created the context for scientific discovery. Focusing on the Old World of Europe, and expanding to the New World of the United States of America, we examine the history of the second half of the nineteenth century. We describe the early efforts where curious people started to try and apply the new phenomenon of electricity. Just as they tried to understand the "nature of lightning" and the "'nature of heat" before[3].

The invention of the Arc Lamp: This segment is about the early form of electric light; the 'arc light' generated by a spark bridging the "Voltaic Gap". Here we describe those early efforts that resulted in the creation of light artifacts that used electricity supplied by the Voltaic Battery (or "wet cell"). Although the Arc Lamp was limited in its performance, it was a miracle for people used to gaslights and candles. We will describe that the breakthrough of the electric light came when the electric dynamo made electricity available in abundance.

The invention of the Incandescent Lamp: We proceed with the development of a radical new artifact; the incandescent light. It is about the symbiosis of the dynamo that created electricity, and the comfortable, warm glow of the incandescent wire bridging the "Voltaic Gap", that consumed the electricity. We describe the efforts of many curious and inventive people, who created the incandescent lamp. A device that was to become a dominant part of the Electric Revolution with its own Industrial Bonanza.

This is a story about the *General Purpose Technology* of "electricity" with its "clusters of innovations" and "clusters of businesses" that created the Era of Light and changed the world we live in.

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[3] See: B.J.G.van der Kooij: *The Invention of the Steam Engine* (2015); *The Invention of Electro-motive Engine* (2015)

The Invention of the Electric Light

Context for the discoveries

For a person in the preelectric era, electricity was a miracle. In those early days, people were used to manual labor, at home and at work. Mainly they were living in the countryside, in hamlets. They were living and working with daylight in poorly lit houses. Our present "evening life" after sunset was a situation nearly incomprehensible for someone living in that world. As so eloquently described by a later inventor of the electric lamp, Joseph Swan (1828–1914):

> *"The days of my youth extend backward to the dark ages, for I was born when the rush-light, the tallow-dip or the solitary blaze of the hearth were common means of indoor lighting and an infrequent glass bowl, raised 8 or 10 feet on a wooden post and containing a cupful of evil smelling train oil with a crude cotton wick stuck in it, served to make darkness visible out of doors. In the chambers of the great the wax candle, or, exceptionally, a multiplicity of them, relieved the gloom on state occasions, but as a rule the common people, wanting the inducement of indoor brightness such as we enjoy, went to bed soon after sunset."* (Spear, 2013a, p. 38)

It is clear that the preelectric era that Swan describes and the era of electricity we live in today are—if only in this respect of lighting—quite different. It may have started with the curiosity of the experimenters, but ultimately it was about a new range of technologies that came about—technologies that created artifacts and systems that produced and consumed electricity. Electricity was the carrier of power and light. It resulted in a society that became completely changed by the new phenomenon of electricity.

> *Of the great construction projects of the last century, none has been more impressive in its technical, economic, and scientific aspects, none has been more influential in its social effects, and none has engaged more thoroughly our constructive instincts and capabilities than the electric power system…Electric power systems embody the physical, intellectual and symbolic resources of the society that constructs them…In a sense electric power systems, like so much other technology, are both causes and effects of social change.* (Hughes, 1993, pp. 1-2)

In hindsight the enormous impact of the introduction of electric light in society is clear. But it took quite some time, many scientific discoveries, and a lot of engineering efforts before this all came to happen within the context that existed in the nineteenth century, especially in the second half of that century, when electric light appeared on the stage.

The second half of the nineteenth century

Europe was in turmoil in period up until the mid-1850s.[4] The wave of European revolutions around 1848 was a temporary revolutionary wave that ebbed away in the next decades. The powers that were part of the original problem, although shaken, were more or less still in place. After the revolutions the emerging middle class and the revolutionary working class were all bitterly disappointed in the short run. But in the long run, it heralded the rise of parliamentary democracy, the disappearance of the former empires, and the diminishing influence of the clergy and nobility.

> *Between 1789 and 1849 Europe dealt with the forces of political revolution and the first impact of the Industrial Revolution. Between 1849 and 1914 a fuller industrial society emerged, including new forms of states and of diplomatic and military alignments. The mid-19th century, in either formulation, looms as a particularly important point of transition within the extended 19th century.*[5]

It was technologically induced changes (and the resulting social changes), but also the political changes (and the social changes that initiated them), that challenged the traditional powers in society—nobility/aristocracy and the clergy. A pattern had developed in the preceding decades over two trajectories: the industrial transformation associated with Britain, and a political transformation associated with France: "Both implied the triumph of a new society, but whether it was to be a society of

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[4] See: B.J.G. van der Kooij: *The invention of the Electromotive Engine* (2015); *The Invention of the Communication Engine* (2015)

[5] Source: http://www.britannica.com/EBchecked/topic/195896/history-of-Europe/58403/Revolution-and-the-growth-of-industrial-society-1789-1914. (Accessed September 2014)

triumphant liberal capitalism, of what a French historian has called the 'conquering bourgeois', still seemed uncertain to contemporaries than to us…the 1830s and 1840s were an era of crisis whose exact outcome only optimists cared to predict" (Hobsbawm, 2010c, p. 14). It was about a society in transaction:

> *In Britain and France the liberals, only half satisfied by the compromises of 1830 and 1832, felt the push of new radical demands from the socialists, communists, and anarchists. Reinforcing these pressures was the unrest caused by industrialization—the workingman's claims on society, expressed in strikes, trade unions, or (in England) the Chartists' demanding "the Charter" of a fully democratic Parliament. Add to these movements those that purposed to stand still or to restore former systems of monarchy, religion, or aristocracy, and it is not hard to understand why the great revolutionary furnace of 1848–52 was a catastrophe for European culture. The four years of war, exile, deportation, betrayals, coups d'état, and summary executions shattered not only lives and regimes but also the heart and will of the survivors.*[6]

That was the general context in the mid-nineteenth century, a context dominated by technical change shaping the Industrial Revolution, a revolution that also had far-reaching social-economic consequences: "The essence of the Industrial Revolution is the substitution of competition for the medieval regulations which had previously controlled the production and distribution of wealth" (Toynbee, 1887, p. 26). Those being the consequences, it was technological change that would be the driving force of the Industrial Revolution.[7]

Europe in the 1848–1875 period

In the second half of the nineteenth century there was a distinct period: "This was the period when the world became capitalist and a significant minority of the 'developed' countries became industrial economies" (Hobsbawm, 2010a, p. 43). It started after the 1848 turmoil—also called the "Springtime of peoples"—that occurred all over Europe and was dominantly characterized by a changing society as the result of the Agricultural Revolution and the first Industrial Revolution:

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[6] Source: http://www.britannica.com/EBchecked/topic/195896/history-of-Europe/58436/The-middle-19th-century.

[7] "The concept of 'Industrial Revolution' will be understood as a period of accelerated structural change in the economy, involving a rapid rise in industrial output, in the share of manufacturing in national product, and in factory-based activity (implying a different kind of economy), **based on major technological innovations**" (Crafts, 1977, p. 432) (boldface mine).

As during the previous half century, much of the framework for Europe's history following 1850 was set by rapidly changing social and economic patterns, which extended to virtually the entire continent. In western Europe, shifts were less dramatic than they had been at the onset of the Industrial Revolution, but they posed important challenges to older traditions and to early industrial behaviours alike. In Russia, initial industrialization contributed to literally revolutionary tensions soon after 1900. The geographic spread of the Industrial Revolution was important in its own right. Germany's industrial output began to surpass that of Britain by the 1870s, especially in heavy industry. The United States became a major industrial power, competing actively with Europe; American agriculture also began to compete as steamships, canning, and refrigeration altered the terms of international trade in foodstuffs. Russia and Japan, though less vibrant competitors by 1900, entered the lists, while significant industrialization began in parts of Italy, Austria, and Scandinavia. These developments were compatible with increased economic growth in older industrial centres, but they did produce an atmosphere of rivalry and uncertainty even in prosperous years.[8]

Geo-political changes

And as always tension between nations led to turmoil, with armed conflicts. Like the Crimean War (1853–1856), where the allied forces of France, Britain, the Ottoman Empire, and Sardinia battled with Russian expansionism. It was about the control of the Black Sea, but in the background loomed the decline of the Ottoman Empire. The Russian threat to the Ottoman Empire required control of the Black Sea, and the key was the Russian naval base at Sevastopol, on the Crimean peninsula.[9]

Figure 1: The Battle of Sevastopol (1854–1855).

Source: Wikimedia Commons, Franze Roubaud.

The Battle of Sevastopol (1854–1855) (Figure 1) concluded the dominance of the czar's Black Sea fleet. It started the fame of the nurse

[8] Source: http://www.britannica.com/EBchecked/topic/195896/history-of-Europe/58446/Summary.

[9] Text based on Wikipedia sources.

Florence Nightingale as the "Lady with the Lamp," treating the many wounded during the battles. The Treaty of Paris (1856) settled the territorial claims for the next fifteen years, a period that lasted till 1870, when the Third French Republic was defeated at the Battle of Sedan. It marked again a period with a lot of turmoil all over Europe. Turmoil that was based on several underlying geopolitical patterns that originated from earlier times.[10]

Figure 2: Embarkation of wounded persons at the harbor of Balaklave, Crimean (1853–1855).

Source: Wikimedia Commons.

Take for example the geopolitical situation in the middle of Europe; there were the independent "German" kingdoms, grand duchies, duchies, principalities, ecclesiastical dominions, and knights' holdings After the defeat of Napoleon, these states were organized in a confederation: the German Confederation ("Der Deutsche Bund," a loose association of thirty-nine German states) (Figure 3). Over time the state Prussia ("Preussen" in figure) had become increasingly powerful, and challenged more and more the former dominance of Austria. It was about the creation of a Greater Germany, either including all German-speaking lands dominated by the Empire of Austria ("Großdeutsche Lösung"), or the Prussian-dominated solution without Austria and southern German states like Luxembourg and Liechtenstein ("Kleindeutsche Lösung"). This conflict was settled in the seven weeks (the "blitzkrieg") of the Austro-Prussian War (June 24–July 22, 1865) when the armies of the Kingdom of Prussia defeated the Austrians.

The Prussian army, being fast to deploy, well-organized, and well-equipped, was the decisive power factor. It was an army that, like Prussia's politics, was dominated by the Junker elite of the landed nobility from the eastern part of the Kingdom of Prussia and their associated culture—the Junkers Bismarck, Roon, and Moltke and soldiers like the generals Albrecht von Roon (1803–1879) and Helmuth von Moltke (1800–1891). The third Junker, the ambassador, statesman, general, and prime minister Otto von Bismarck, dominated with his diplomacy German and European affairs from the 1860s until 1890. "If Prussia ruled Germany, the Junkers ruled Prussia, and through it the Empire itself." (Ogg, 1918)

[10] See: B.J.G. van der Kooij: *The Invention of the Communication Engine*. (2015)

Figure 3: The German Confederation (1815–1866)

Map shows the territories that were part of "Der Deutsche Bund" during 1815–1866.

Source: Wikimedia Commons, Based on Putzger: Historische Weltatals.

The Peace of Prague (1866) settled the conflict. Bismarck's diplomatic efforts avoided harsh terms (Austria only lost Venetia). Prussia gained control over the other participants in the North German Confederation of some twenty-two states, and Austria became excluded from "Germany." The Southern German Confederation, although planned for, never came into existence. Soon the southern states were stimulated to join the northern states. That unification took another four years of legislation, the Franco-Prussian War of 1870–1871, and the Siege of Paris in 1871 before the Prussian King Wilhelm I (1797–1888) was proclaimed German Emperor in the Palais de Versailles. It marked the start of the Second German Empire (1871–1918), with a Constitution (the "Reichstag") that started German's transition into a parliamentary monarchy.

A second geopolitical element in the turmoil was located in Southern Europe, where the Austrian Empire (the "Kaisertüm Oestereich") was defeated in 1866 in the Austro-Prussian War. The once-so-powerful Habsburg monarchy unified in the Austrian Empire, created in 1804 and spanning a territory from present-day Italy to the Balkans, became the Austro-Hungarian Empire in 1867 (Figure 4). A change into a Dual Monarchy administered from Vienna and Budapest, that influenced the traditionally large Austrian influence in Northern Italy.

Figure 4: The Austro-Hungarian Empire (1814–1914)

Map shows the territories that were part of the Austro-Hungarian Empire. Source: www.philatelicdatabase.com/.

Then, today's Italy was a conglomeration of former city-states (Turin, Bergamo, Padua Venice, Florence, Parma, etc.) that had developed into a range of regional states like the Kingdom of Sardinia, the Grand Dutchy of Tuscany, the Duchy of Modena, the Kingdom of Lombardy-Venetie, the Kingdom of Naples, and the Papal States. Often they were dominated by foreign royalty from France, Spain, and England (Figure 5). They had histories with rich and powerful political dynasties like the house of Medici, who financed as bankers the warring kings (Hibbert, 1979).

It was the Italian Unification during the nineteenth century that brought these states together into the single Kingdom of Italy after the Congress of Vienna in 1815. This was a period of continuous political upheaval, revolutionary movements, and insurrections. The first Italian Independence War (1848–1849) occurred when the Kingdom of Sardinia, together with the Papal States and the Kingdom of the two Sicilies, declared war against Austria, which dominated the northern regions. They lost, the revolutions were crushed, and the Austrians restored (their) order in northern and

Figure 5: Italy before the Unification (1843)

Map shows the different nation-states and territories.

Source: Wikimedia Commons.

central Italy. It was not to last long, as in the second Italian Independence War (1859), Napoleon III joined in and defeated Austria in the Battle of Magenta and the Battle of Solferino. After some more conflicts in 1861, Victor Emmanuel was proclaimed king of Italy, and Rome was declared the capital of Italy. But it would need the third Italian Independence War (1866) to create a (more or less) unified Italy in 1870. All after the collapse of the Habsburg Empire with the "Compromise of 1867" and the collapse of the Second French Empire in the Battle of Sedan (1870).

That was—in large brushstrokes—a painting of some of the geopolitical context in Europe during the nineteenth century.

But there was also a technical context, as this was the war in which (electric) technology started to play a role. The Crimean War, considered to be the first modern, industrialized, and technology-dominated war, saw the use of mass-produced rifles, exploding shells, sea mines, and armoured coastal assault vessels with long-range cannons. Also, the steam engine altered the dynamics of the battlefield, with its transportation facilities on sea and on land. It would make people like James Watt, the "inventor of the steam engine," and other industrialists (Bezemer, Cort) become, next to traditional generals and noblemen, part of the circle of "heroes of the nation."

Figure 6: The Crimean War region (1853–1856).

Map shows the Crimea area with the Telegraph Cable between Varna and Balaklava. From Varna it ran to Constantinople where it was connected to the international telegraph network

Source: map adapted by author

> *The Crimean War marked the first time in modern military history that the Industrial Revolution had an observable and powerful consequence for the conduct of war…Steam power was undoubtedly put to the test during the Crimean War and it was a profound success on and off the battlefield…The advent of the telegraph, photography, and other related technologies enabled, for the first time, societies to see directly what war looked like. This seemingly innocuous ability had major ramifications for both the military as well as society…The steam engine and telegraphy in particular—the two main technologies behind these transformations—led to a series of major changes both on the battlefield and within society as a whole.* (Voytek, 2011)

Next to steam power, the newly arising technology of electricity played a role. For example in communications, a 547 km submarine cable between Balaklava and Varna in April 1855 was installed and connected to the telegraph hub in Constantinople (Figure 6).[11] It had quite some consequences:

> *This was also the first major war since Samuel Morse's inventions enabled communication over long distances via telegraph. The French and British laid lines from their Crimean HQs to Paris and London, the first time political leaders could directly contact their armies in foreign theatres. Newspaper war correspondents got reports back to Britain and France from the front line via telegram within five days. They sent photographs home too, and the British public saw for themselves the terrible conditions wounded soldiers had to endure. Nurses like Florence Nightingale and Mary Seacole became heroines and the first British nursing school opened in 1860.*[12]

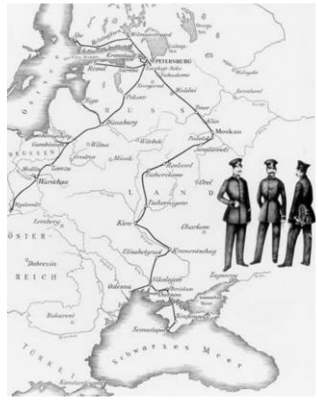

Figure 7: The telegraph line between St. Petersburg and the Crimean (1853–1855).

Source: http://www.skyscrapercity.com/showthread.php?t=1431673&page=2.

The Russians also had their communication needs. In Russia the young Ernst Werner Siemens, only recently active as an entrepreneur, had installed a telegraph connection between St. Petersburg and Crimea (Figure 7).

> *Siemens, having left the army, visited Russia and planned an extensive telegraph network, including a line from St. Petersburg to the Crimea, used during the Crimean War. The Russian business was so extensive that Siemens' brother Carl was made resident Russian representative, and so profitable that Siemens could conduct research that resulted not only in telegraph improvements but also in advances in underwater cable telegraphy.*[13]

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[11] For more detail, see http://atlantic-cable.com/Cables/1855Crimea/. (Accessed November 2014).

[12] Source: http://eandt.theiet.org/magazine/2013/10/the-first-modern-war.cfm. (Accessed November 2014).

[13] Source: http://www.encyclopedia.com/topic/Ernst_Werner_von_Siemens.aspx. (Accessed November 2014).

Social change

This description illustrates the Crimean War, one of the many wars in that period of that time, and it also illustrates the role of technology. The combination of warfare and technology resulted in shifting powers leading to social change, often with considerable turmoil. But that turmoil was not felt everywhere. In large parts of Europe, life was “normal”; during the second half of the nineteenth century, the “middle class of the bourgeois” developed and sought its place between nobility and the peasantry. And the peasantry went with the ebb and tide of the climate. One of the consequences was the demographic transition that took place.

The third quarter of the nineteenth century shows a demographic pattern that could be seen all over Europe. The population still existed overwhelmingly of peasants; in Europe the rural population largely prevailed over the urban. But the cities were growing, an urbanization that was the result of the industrialization, where factories took over the traditional forms of production. Industrial growth was also supplied by a growing agricultural economy, both combined with national and international trade. It was the changing transport infrastructure and the steam engine that had made it possible to transport raw materials (cotton, grain) and finished goods (machines, tools). The United States shipped to Europe, and Europe shipped to the United States. The colonies brought their commodities to both—all by steamboat. And locally the steam locomotive linked producers to their markets. Given this overall picture, some characteristics were quite dominant:

Increasing global trade and industrialization: As the result of the industrialization and the related effects in society (like the emerging middle class, which had money to spend), the economy flourished. “Never, for instance, did the British exports grow more rapidly than in the first seven years of the 1850s” (Hobsbawm, 2010a, p. 44). That was the export side, but it influenced the import side as the cotton mills needed cotton imported from America. Remarkably enough, this *Victorian Boom* would result in the first economic crisis that was not related to war: the *Panic of 1857*. A financial crisis—starting in the United States—was related to a range of causes: railroad extension, land speculation, grain prices, grain exports, and the aftermath of the Crimean War. “Indeed, it almost appeared that the prosperity of the American farmer required Europeans either to be at war or suffering a famine” (Huston, 1983, p. 19). We will go more in detail on these interrelated technical, economic, and social changes further on.

Changed scientific thinking: But there were, next to the technical, social and political changes, more characteristics for this period.[14] For example, in *scientific thinking*, the naturalist philosophies were slowly replaced when it became clear that simple mechanistic explanations based on "dead" matter were inadequate: "The decline of the machine analogy had its counterpart in the biological sciences. With narrow Darwinian dogmas in abeyance, the genetics of Gregor Mendel were rediscovered, and a new science was born. The fixity of species was again regarded as important…while the phenomenon of large mutations…caught the public imagination, just as the slow, small changes had done 60 years earlier. The elusive 'fitness of the environment' was being considered of as much importance in the march of evolution as the fitness of the creature."[15]. This development in scientific thinking will also be a topic for further exploration later on.

The emergence of capitalism: Whether or not influenced by the great gold discoveries in California, Australia, and other places after 1848 (that resulted in increasing gold coinage issued by the governments of the United States, Britain, and France), it is fact that capital based on the gold standard became readily available (Hobsbawm, 2010a, p. 50). It created the capitalistic economy, an economic structure in which trade, industry, and the means of production are largely or entirely owned and operated for profit, dominantly by non-state institutions. After the Commercial Revolution of the eighteenth century—with its colonialism, mercantilism, and protectionism—and the Industrial Revolution of the nineteenth century, with its industrialization and factorization, capitalism was becoming the dominant characteristic of the Western world. Although in different forms, it had the monetary system as the basic

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[14] Take the change in economic thinking. It was Karl Marx, being occupied with his research in political economy, who linked the economic development with societal development. *"Marx worked out his ideas on various aspects of political economy in close connection with general philosophical questions of the revolutionary world outlook. Regarding production relations as the economic basis of social development, Marx went on to examine processes at work within the political and ideological superstructure, pointing out their dependence on the basis and their reaction on the basis"* (Marx & Engels, 1986, p. XV). He created the first draft of his famous book *Das Capital* (1867) with these observations and reflections made in 1857–1858. It was another way of economic thinking about "industrial capitalism." "*Marx rises above the limitations of the bourgeois economists, including the classical economists, who confined the tasks of economics to the study of relations of distribution. His analysis of the dialectical unity and interaction of production, distribution, exchange and consumption leads Marx to conclude that production is not just the point of departure but also the decisive moment of this unity and that the forms of distribution are merely an expression of the forms of production. Thus the production relations between men, and the laws governing the development of a given mode of production, constitute the true subject matter of economics"* (Marx & Engels, 1986, pp. XIV-XV).

[15] Source: http://www.britannica.com/EBchecked/topic/195896/history-of-Europe/58465/New-trends-in-technology-and-science. (Accessed November 2014)

element. The availability of capital, combined with private ownership, combined with the system of stock markets used for raising capital for corporations. It facilitated in the great global economic boom of the 1850s, also called the *Great Victorian Boom* (Church, 1975).

> *What made this boom so satisfactory for profit-hungry businessmen was the combination of cheap capital and rapid rise in prices…And the businessmen were not the only ones to benefit…employment grew by leaps and bounds, both in Europe and overseas, whither men and women now emigrated in enormous numbers…The political consequence of this boom was far reaching…politics went into hibernation.* (Hobsbawm, 2010a, p. 45)

The mix of technology and science, economy, capitalism, and political reform was dynamic, and the third quarter of the nineteenth century certainly brought change. It was a period that the historian Eric Hobsbawm characterized as the "Age of Capital 1848–1875" : "It was the triumph of a society which believed that economic growth rested on competitive private enterprise, on success market (including labour) and selling in the dearest. (Hobsbawm, 2010a, p. 13)

Europe in the 1875–1914 period

The last quarter of the nineteenth century saw, in its turn, another range of drastic changes. Describing the next period to come after the "Age of Capital", Hobsbawm noted:

> *In the first place, we enter now a new technological era, no longer determined by the inventions and methods of the first Industrial Revolution: an era of new sources of power (electricity and oil, turbines and the internal combustion engine), of new machinery based on new materials (steel, alloys, non-ferrous metals), of new science based industries, such as the expanding organic chemical industry. In the second place we now increasingly enter the economy of the domestic consumer market, pioneered in the United States, fostered not only…by rising mass incomes, but above all by the sheer demographic growth of the developed countries…In the third place…the post-liberal era was one of international competition between rival national industrial economies—the British, the German, the North-American…Competition thus led towards economic concentration, market control and manipulation…The world entered the period of imperialism…The new technological industries required such materials; oil, rubber, non-ferrous metals.* (Hobsbawm, 2010a, pp. 355-356)

It was in the last quarter of the nineteenth century that the relative peace and tranquillity created the *Victorian/Edwardian Era* (Britain), the *Gilded Age* (America), and *La Belle Époque* (France). These were the times of relative progress that lasted till the Great War (World War I) erupted. Times when the fruits of earlier technical developments (e.g., in electricity) became visible (i.e., electric light, telegraphy, telephony) in the broader parts of society. As the historian Eric Hobsbawm characterizes this period in his book "Age of Empire 1875–1914":

> *In the 1880s Europe was not only the original core of the capitalist development which dominated and transformed the world, but by far the most important component of the world economy and of bourgeois society. … From the middle of the 1890s until the Great War, the global economic orchestra played in the major key of prosperity rather than, as hitherto, in the minor key of depression. Affluence based on booming business formed the background to what is still known on the European continent as the "beautiful era" (belle époque).* (Hobsbawm, 2010b, pp. 18, 46)

Describing the characteristics of the world economy, Hobsbawm observes (next to the globalization and international trade, and the increasing state rivalry) the role of technological innovation, organizational innovation, and market innovation:

> *The third characteristic of the world economy is at first sight the most obvious: technological revolution. This was, as we all know, the age when the telephone and the wireless telegraph, the phonograph and the cinema, the automobile and the aeroplane, became part of the scenery of modern life, not to mention the domestication of science and high technology by means of such products as the vacuum cleaner (1908) and the only universal medicament ever invented, aspirin (1899).* (Hobsbawm, 2010b, p. 52)

> *The fourth characteristic was…a double transformation in the structure and modus operandi of capitalist Enterprise. On the one hand there was the concentration of capital, the growth in scale which led men to distinguish between "business" and "big business" (Grossindustrie, Grossbanken, grande Industrie…), the retreat of the free competitive market, and all the other developments which, around 1900, led observers to grope for general labels to describe what plainly seemed to be a new phase of economic development. On the other, there was the systematic attempt to rationalize production and the conduct of business enterprise by applying "scientific methods" not only to technology but to organization and calculation.* (Hobsbawm, 2010b, pp. 52-53)

> *The fifth characteristic was an extraordinary transformation in the market for consumer goods: a change in both quantity and quality. With the growth of population, urbanization and real incomes, the mass market, hitherto more or less confined to foodstuffs and clothing, i.e. to basic subsistence needs, began to dominate the industries producing consumer goods.* (Hobsbawm, 2010b, p. 53)

He concluded that this Belle Époque in the period up to World War I was having some profound characteristics of transition, transformation, and progress—although not progress for everyone:

> *In short, the new colonialism was a by-product of an era of economic-political rivalry between competing national economies, intensified by protectionism…In the retrospective mythology of the working classes, the decades before 1914 do not figure as a golden age, as they do in those of the European rich and even of the more modest middle classes. For these, indeed, the belle epoque was the paradise that was to be lost after 1914…Yet the Age of Empire was not only an economic and political but a cultural phenomenon. The conquest of the globe by its "developed" minority transformed images, ideas and aspirations, both by force and institutions, by example and by social transformation.* (Hobsbawm, 2010b, p. 76)

Part of that "cultural phenomenon" was reflected in the political change that took place. It was the result of a democratization process that was heralded by the French Revolution and affirmed by the 1848-Revolutions. Even after the dramatics of the French Revolutions, that were felt all over Europe, the ruling classes (royalty, nobility, clergy) might have resisted the changes for a long time. But after the 1870s political change was inevitable.

> *Yet after 1870 it became increasingly clear that the democratization of the politics of states was quite inevitable. The masses would march on to the stage of politics, whether rulers liked it or not…Even if contemporaries did not know what was to come after, they often had the sense, in these last pre-war years, of society trembling as under seismic shocks before greater earthquakes. These were years when wisps of violence hung in the air over the Ritz hotels and country houses. They underlined the impermanence, the fragility, of the political order in the belle epoque.* (Hobsbawm, 2010b, pp. 85, 109)

In was in the last quarter of the nineteenth century that a different political structure was shaped: it was characterized by the rise of the democratic parliamentary system, and the influence of the Catholic Church in places being forcedly opposed.

> *With the emergence of the Third Republic, the constitutional structure of western Europe was largely set for the remainder of the 19th century. All the major nations (except Spain, which continued to oscillate between periods of liberalism and conservative authoritarianism) had parliaments and a multiparty system, and most had granted universal manhood suffrage. Britain completed this process by a final electoral reform in the mid-1880s. Belgium, Italy, and Austria held out for a longer time, experiencing considerable popular unrest as a result, though voting reforms for men were completed before 1914. Important political crises still surfaced. Bismarck warred with the Roman Catholic church and the Catholic*

> *Centre Party during the 1870s before reaching a compromise agreement. He then tried virtually to outlaw the socialist party, which remained on the defensive until a liberalization after he fell from power in 1890. During the 1890s, France faced a major constitutional crisis in the Dreyfus affair. The imprisonment of Alfred Dreyfus, a Jewish army officer falsely accused of treason, triggered a battle between conservative, Catholic, and military forces, all bent on defending the authority of army and state, and a more radical republican group joined by socialists, who saw the future of the republic at stake. The winning pro-Dreyfus forces forced the separation of church and state by 1905, reducing Catholicism's claims on the French government and limiting the role of religion as a political issue.*[16]

Let's have a look at some of the characteristics for the main players that set the stage for the (technological) development to come: Britain, France, and the United States of America. Not that there were no relevant developments elsewhere (such as in Germany and Russia), but limiting ourselves to these players should illustrate the context for innovation quite adequately.

England's Victorian/Edwardian Era

In England in the second half of the nineteenth century, a lot was going on politically, socially, and religiously. As the originator of the Industrial Revolution,[17] in Britain these changes were embedded in its global power: the so-called *British Empire* (Figure 8). Shaped already before the period we

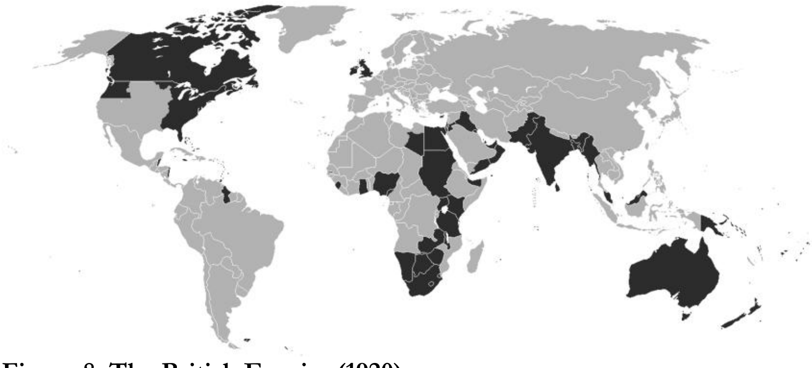

Figure 8: The British Empire (1920)

Map shows (in dark) the territories that were at one time or another part of the British Empire.

Source: Wikimedia Commons.

[16] Source: http://www.britannica.com/EBchecked/topic/195896/history-of-Europe/58451/Conditions-in-eastern-Europe. (Accessed November 2014)

[17] See: B.J.G. van der Kooij: *The Invention of the Steam Engine.* (2015)

consider here, the British Empire was at its peak in the latter half of the Victorian Era (1837–1901) and the Edwardian Era (1901–1914), which coincided with the Belle Époque era (1871–1914). It was the global spread of the British Empire that—by 1922—held sway over about 458 million people, one-fifth of the world's population at the time.

How did it come about? To just touch on this question, we have to realize that in England were the roots of the first Industrial Revolution.[18] It was the eighteenth century development of the steam engine and its mobile and stationary applications (steamboat, steam locomotive, stationary steam machine) that fuelled the change from "natural power" (human, animal, wind, and water) to "steam power". So in the nineteenth century, we find England in a massive transition from a feudal state to an industrialized state.[19]

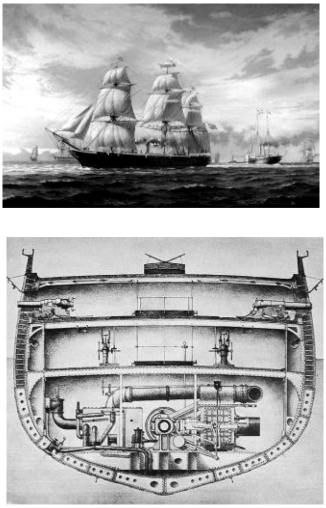

Figure 9: HMS *Warrior* (1861) under sail (top) and the steam engine (bottom).

Source: http://www.bbc.co.uk/arts/yourpaintings/paintings/hms-warrior-escorting-the-royal-yacht-victoria-and-albert-25525. S. Francis Smitheman.

In the mid-nineteenth century, the first Industrial Revolution was in full swing. But at the horizon loomed the second Industrial Revolution. That was the transition caused by the development of the electro-motive engine.[20] So the Industrial Revolutions created the means for England's foreign policies. England, with its growing population, had already had for centuries a policy of expansion and imperialism.[21] Its goal was not only to trade lucratively, but also to populate its colonies with the overflow of its expanded population.[22]

In the nineteenth century, "*Britannia ruled the waves*" as the result of a massive Royal Navy that was strong enough "to make the political weather" wherever it went (e.g., the Battle of Trafalgar, 1805). This situation even improved

[18] The expression "Industrial Revolution" is used to describe "*a period of accelerated structural change in the economy, involving a rapid rise in industrial output, in the share of manufacturing in national product, and in factory-based activity (implying a different kind of economy), based on major technological innovations*" (Crafts, 1977, p. 431).
[19] See: B.J.G. van der Kooij: *The invention of the Steam Engine.* (2015)
[20] See: B.J.G. van der Kooij: *The invention of the Electromotive Engine.* (2015)
[21] Imperialism is defined as a policy of extending a country's power and influence through colonization, use of military force, or other means (Oxford Dictionaries).
[22] In the late eighteenth and nineteenth centuries, large numbers of convicts were transported to the various Australian penal colonies.

when the new technology of steam power was applied by the navy, which created iron ships like the HMS *Warrior* (1859-1861) (Figure 9), powered by sail and a two-cylinder trunk steam engine, and full steam-powered ships like the HMS *Devastation* (1871).

> *The "destructive force" of the Royal Navy did not have to be deployed often in order to be an effective tool in global politics. In the heyday of British influence it was often an unspoken fact. "Showing the flag" in distant corners of the planet was among the Navy's most important roles…This meant mastering the age of steam…Steam power's great advantage lay in its ability to bring ships of war close to land, where they could blockade ports, bombard cities, harbours, roads, and forts. This was a kind of warfare unknown in the age of sail, when wind and tide and the dangers of a lee shore made station-keeping difficult.* (Wilson, 2013)

British Colonialism in the Nineteenth Century[23]

What would later become the British Empire started in the *Age of Discovery* (from the fifteenth century onward), when the Brits sailed the oceans, like the Portuguese, Spanish, Dutch, and many others, and created their first trading posts and established their first overseas possessions, called the colonies. Just to highlight some of the events that created the British Empire, there were the following developments noticeable:

It was in the nineteenth century that the colonial expansion in South Africa took place. In 1806 Britain had acquired the former Dutch Cape colony controlled by the *Dutch East India Company* after the Battle of Muizenberg (1795) and the Battle of Blaauwberg (1806). The original trading post supplied the Dutch merchant ships travelling to the Far East and eventually was colonized with Dutch settlers. In 1814 the colony was ceded outright by Holland to the British crown. Later the descendants of the former Dutch Boers, who were as dissatisfied with British rule as they had been with that of the Dutch East India Company, fled (the *Great Trek*) to settle elsewhere outside British rule. But that is a completely different story…

Figure 10: Political cartoon of Benjamin Disraeli making Queen Victoria Empress of India (1876).

Source: Wikimedia Commons, John Tenniel in *Punch Magazine*, April 15, 1876.

It was the *East India Company* that drove the expansion of the British empire in Asia. Britain rivalled with Russia for supremacy in

[23] Text and content based on several Wikipedia sources.

Central Asia in the "Great Game." It resulted in British dominance in Afghanistan (the first Anglo-Afghan War, 1839–1842). This expanded with the "British Raj," the end of the control of the East India Company and establishing the British crown rule of the Indian subcontinent (1858–1914). This originated in the "Indian Mutiny" of 1857 and resulted in the ruling of India directly through Britain's representative, called the governor general. It made India a part of the British Empire, and in 1876 Queen Victoria was proclaimed Empress of India (Figure 10).

The British sphere of influence also expanded in the Middle East. After the opening of the *Suez Canal* in 1869, Britain recognized the importance of the canal. The Suez Canal had an immediate and dramatic effect on world trade. Combined with the American transcontinental railroad, completed six months earlier, it allowed the world to be circled in record time. It played an important role in increasing European colonization of Africa. The construction of the canal was one of the reasons for the *Panic of 1873*, because goods from the Far East were no longer carried in sailing vessels around the Cape of Good Hope and were no longer stored in British warehouses. Not much later the Anglo-Egyptian War (1882) vastly expanded British influence over the country. Starting with outright occupation, changing over time in character, it would last till the Egyptian revolution of 1952, which eliminated the British military presence. "The occupation illustrates how the emergence of a particular configuration of economic and political forces in Britain found expression abroad after 1850" (Hopkins, 1986, p. 391).

Much more could be told about the British Empire in the times of colonization and imperialism[24]. But these few examples already show both the context for the following development of the Age of Electricity, as well as the influence all those technical changes had in the sustaining and expansion of the British Empire. Remarkably the British imperial strength

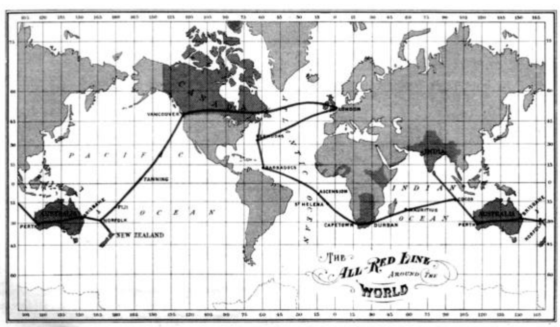

Figure 11: The "All Red Line" infrastructure of the telegraph network linking the British Empire (1902).

Source: Wikimedia Commons, George Johnson (1836–1911), The All Red Line—The Annals and Aims of the Pacific Cable Project.

[24] See: B.J.G.van der Kooij: *The invention of the Communication Engines.* (2015)

was underpinned by the steamship and the telegraph, new technologies invented in the second half of the nineteenth century, allowing it to control and defend the empire. By 1902 the British Empire was linked together by a network of telegraph cables, the so-called “All Red Line” (Figure 11).

Social change in Britain

Nineteenth-century Britain had seen a massive increase in its population, accompanied by rapid urbanization and industrialization. Social classes were divided; on the one hand were the former *upper class* of the nobility and landowning class, on the other hand the poor *working class* living in slums. In between were the emerging *middle class* of the citizens: the merchants, shopkeepers, and industrialists. For middle-class women, their role was a domestic one that centred around family, motherhood, and respectability. For the lower class, child labour was common in factories, cotton mills, and mines.

> *For wage labourers, the autonomy of work declined; more people worked under the daily direction of others. Early textile and metallurgical factories set shop rules, which urged workers to be on time, to stay at their machines rather than wandering around, and to avoid idle singing or chatter (difficult in any event given the noise of the equipment). These rules were increasingly enforced by foremen, who mediated between owners and ordinary labourers. Work speeded up. Machines set the pace, and workers were supposed to keep up…The growth of cities and industry had a vital impact on family life. The family declined as a production unit as work moved away from home settings.*
>
> *This was true not only for workers but also for middle-class people. Many businessmen setting up a new store or factory in the 1820s initially assumed that their wives would assist them, in the time-honoured fashion in which all family members were expected to pitch in. After the first generation, however, this impulse faded, in part because fashionable homes were located at some distance from commercial sections and needed separate attention. In general, most urban groups tended to respond to the separation of home and work by redefining gender roles, so that married men became the family breadwinners (aided, in the working class, by older children) and women were the domestic specialists.*[25]

Political change in Britain

Britain, for its expansion policies, needed free trade, not only at home, but also abroad. At home the population more and more protested against the *Corn Laws*; laws enabling tariffs on imported grain during the early to mid-1800s, designed to keep cereal prices high to favor producers in Great

[25] Source: http://www.britannica.com/EBchecked/topic/ 195896/history-of-Europe/58406/Social-upheaval. (Accessed November 2014)

Britain itself. For the trade abroad, the protests were against the *Navigation Acts*, a series of laws that restricted the use of foreign ships for trade between Britain and its colonies. It was all about the abolishment of protectionism.

> *By the mid-19th century, Britain was firmly wedded to the notion of free trade and the first era of globalization began. In the 1840s, the Corn Laws and the Navigation Acts were repealed, ushering in a new age of free trade. In line with the teachings of the classical political economists, led by Adam Smith and David Ricardo, Britain embraced liberalism, encouraging competition and the development of a market economy.*[26]

So, free trade became a central element in the British policies. It would play a key role in the economic growth and financial dominance of Britain after the 1840s.

The political dimension of the Victorian Era (1837–1901) more or less started with the *Reform Act of 1832*, where the electoral systems of England and Wales were "reformed," that is, the power balance shifted from the aristocracy to the middle class:

> *The Act granted seats in the House of Commons to large cities that had sprung up during the Industrial Revolution, and removed seats from the "Rotten Boroughs"—those with very small electorates and usually dominated by a wealthy patron…As The Reform Act did very little to appease the working class, since voters were required to possess property worth £10, a substantial sum at the time. This split the alliance between the working class and the middle class, giving rise to the Chartist Movement.*[27].

But the lower, working class also demanded its rights as the Chartists were demanding "the charter" of a fully democratic Parliament. "On 10 April 1848, a new Chartist Convention organised a mass meeting on Kennington Common, which would form a procession to present a third petition to Parliament…It was not until 1867 that urban working men were admitted to the franchise under the Reform Act 1867, and not until 1918 that full manhood suffrage was achieved."[28] Now the urban working class also got their democratic rights, except the women who would fight their cause later on.

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26 Source: Wikipedia: http://en.wikipedia.org/wiki/History_of_capitalism#Industrial_capitalism. (Accessed November 2014)
27 Source: Wikipedia: http://en.wikipedia.org/wiki/Reform_Act_1832. (Accessed November 2014)
28 Source: Wikipedia: http://en.wikipedia.org/wiki/Chartism#Mid-Forties. (Accessed November 2014)

Technical change in Britain

In England the Industrial Revolution was full underway. The steam engine had its effect on transportation and transport infrastructures. Railroads enabling goods and passenger trains had erupted (after the *Railway Mania* in the 1840s). Trade and industry were facilitated by a network of railroads transporting goods, raw materials, and people. And steamships made international travel possible on an increasing scale. In that context we see the Victorians, who were impressed by science and progress. Darwin had published his *Origin of Species* in 1859. Gaslight had spread in the cities. And when electricity and the arc lamp came about, the demonstration projects drew huge crowds of spectators.

London had its great exhibitions like elsewhere in the world—like the *Great Exhibition of the Works of Industry of all Nations* (1851), showing the telegraph, microscopes, air pumps, and barometers in the Crystal Palace building (Figure 12). It was opened by Queen Victoria and visited by 6 million people. One of them was the writer Charlotte Bronte:

> *"Yesterday I went for the second time to the Crystal Palace. We remained in it about three hours, and I must say I was more struck with it on this occasion than at my first visit. It is a wonderful place—vast, strange, new and impossible to describe. Its grandeur does not consist in* one *thing, but in the unique assemblage*

Figure 12: The Crystal Palace at the 1851 Exhibition.

Source: http://www.mackinac.org/ article.aspx?ID=4999, Lawrence W. Reed.

of all *things. Whatever human industry has created you find there, from the great compartments filled with railway engines and boilers, with mill machinery in full work, with splendid carriages of all kinds, with harness of every description, to the glass-covered and velvet-spread stands loaded with the most gorgeous work of the goldsmith and silversmith, and the carefully guarded caskets full of real diamonds and pearls worth hundreds of thousands of pounds. It may be called a bazaar or a fair, but it is such a bazaar or fair as Eastern genii might have created. It seems as if only magic could have gathered this mass of wealth from all the ends of the earth—as if none but supernatural hands could have arranged this, with such a blaze and contrast of colours and marvellous power of effect. The multitude filling the great aisles seems ruled and subdued by some invisible influence. Amongst the thirty thousand souls that peopled it the day I was there not one loud noise was to be heard, not one irregular movement seen; the living tide rolls on quietly, with a deep hum like the sea heard from the distance.“*[29]

This successful exhibition was soon to be followed by its little brother, the *1862 International Exhibition* and later by the *Annual International Exhibitions* (e.g. 1871, 1872).

Consumerism

Due to the rising middle class and its improving economic situation, people had more to spend. The fruit of industrialization was the availability of a vast array of new products (clothing, glass and tableware). Mass production made attractive pricing possible. On the other hand, colonialism also brought more products (tobacco, tea, coffee). It resulted in the advent of the department store.

Figure 13: Selfridges on the day of its opening in 1909.

Source: http://www.theguardian.com/lifeandstyle/2009/apr/30/selfridges-centenary-shopping-oxford-street.

For the first time, customers could buy an astonishing variety of goods, all in one place, and shopping became a popular leisure activity. While previously the norm had been the scarcity of resources, the Industrial era created an unprecedented economic situation. For the first time in history products were available in

[29] Source: The Brontes' Life and Letters, by Clement Shorter (1907). (Accessed November 2014)

outstanding quantities, at outstandingly low prices, being thus available to virtually everyone in the industrialized West.[30]

Like the Grand Magasins in Paris, London also saw the appearance of department stores. Originating from the 1830s (Harrod's in 1834, Bainbridge's in 1838), they developed later into stores like Selfridges (1909) (Figure 13) in Oxford Street, which promoted the radical notion of shopping for pleasure rather than necessity.

> *To attract respectable middle-class women into the center, the expanded fashion emporia offered a series of services and comforts that would recreate a homelike atmosphere: restaurants, restrooms, and writing rooms, and elegantly attired shop girls who were quick to "understand" what other women "want" and to enter into the "little troubles" of their customers…In the late Victorian period, department stores developed alongside a network of commercial entertainment and services: inexpensive tea shops, public lavatories, ladies clubs, cheap public transport, and theatre matinees. These facilities allowed female consumers to enter the city and to enjoy a "shopping day" while still maintain their respectability.* (Walkowitz, 1998, p. 5).

America: Revolution and the Gilded Age

Not only in Europe was the mid-nineteenth century a period of turmoil. In the United States, the *Civil War* raged from 1861 to 1865 due to the issue of slavery, which created the secession of several Southern states to create the *Confederate States of America*. More than 600,000 people died, and the war destroyed much of the wealth that had existed in the South. All accumulated investment Confederate bonds were forfeit; most banks and railroads were bankrupt. But there was already much that took place in the American society and economy preceding the outburst of the Civil War.

Technical, economic, and social change interwoven

Take the *Panic of 1857*, which brought in the United States a financial crisis and the world a global economic recession in 1850–1860s; it was related to the emerging railroad infrastructure in the United States, like the *Transcontinental Railroad*, a landmark of "Western Expansion" (Figure 14). "It was well known at the time that many railroads, particularly railroads located in middle and western states, were highly levered and faced with declining revenues due to a drop in agricultural commodity demand as well as increased competition" (Riddiough & Thompson, 2012, p. 2).

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[30] Source: http://en.wikipedia.org/wiki/Consumerism#Origins

That the world economy had become quite interlinked can be seen in the following observation:

Figure 14: The last spike: celebration of completion of the First Transcontinental Railroad (1869).

Source: Wikimedia Commons.

> *One Indiana writer noted that prices would not rise for agricultural products in the European markets because Russia, freed from the demands of war, "will have millions of bushels* [of wheat] *for exportation." The practical effect of the lack of European demand was that even when western cereals were sent East, they were not sold to overseas customers but merely warehoused."…*[After the abolishment of the British Corn Law in 1846] *England was by far the greatest foreign purchaser of American grains, but even so the English still raised nearly three-fourths of their own food and imported the remaining one-fourth largely from France, Russia, Prussia, and other Central European states. The Crimean War disrupted the Central European sources of grain and so England momentarily turned to the American Northwest. When the war ended, Russia and other Central European wheat-producing regions swiftly reasserted their position in the English market.* (Huston, 1983, pp. 16, 27)

Whatever the exact reasons, there certainly was a lot of speculative investment, in railroad construction and also in land where the projected railroads were to be constructed.

> *As early as 1854, older locally oriented roads in the West found their earnings falling and their opportunities shrinking, as a result of competition from the new trunk lines. These new lines, with their aggressive land-purchasing policies and far-reaching plans for transcontinental expansion, provided the principal speculative opportunities for railroad investors of the 1850s. Their fortunes depended on a continuing inflow of settlers and the growth of commerce on the frontier, which required confidence in the viability of expansion westward.* (Calomiris & Schweikart, 1991, p. 810)

It was the failure of the *Ohio Life Insurance and Trust Company*[31]—a shadow bank not conforming to contemporary banking standards within the free banking era of 1840-1850s—that financed largely in railroad bonds and stocks that triggered the stock market panic. Railroad share prices especially took a dive. Problems on the stock market always influenced bank positions. So, New York City banks followed soon and took a dive of their own.

> *On October 3 the respected firm of E.W. Clark, Dodge, and Company failed…On October 10, however, the surprised New York market saw several railroad companies and the securities firm Corning and Company fail…When New York City banks opened for business on October 13, an unprecedented run by depositors greeted them. Before agreeing to suspend, the banks paid out between $4 million and $5 million. Wall Street literally was filled with depositors hurrying to withdraw their funds. The banks went down before a storm they could not postpone or resist.* (Calomiris & Schweikart, 1991, pp. 821-822)

The *Panic of 1857* disrupted the banking system (concentrated in the Wall Street in New York), which was interwoven with the real economy (Figure 15). And the "real economy" had a dynamics of its own, with disruptions and cyclic behaviours caused by social dynamics like the brewing unrest between Northern and Southern states.

Figure 15: The Panic in Wall Street (1857).
Source: Harper's Weekly (October 10, 1857).

> *The United States had become a nation of two distinct regions. The free states in New England, the Northeast, and the Midwest had a rapidly growing economy based on family farms, industry, mining, commerce and transportation, with a large and rapidly growing urban population. Their growth was fed by a high birth rate and large numbers of European immigrants, especially British (in particular, Irish) and German. The South was dominated by a settled plantation system based on slavery. There was some rapid growth taking place in the Southwest, (e.g. Texas), based on high birth rates and high migration from the Southeast, but it had a much lower immigration rate from Europe. The South also had*

[31] "Given Ohio Life's immediate western railroad connections, and that at least one-fourth of its capital was tied up in a single faltering western road…it is understandable that of all the banks in the country Ohio Life would be first to fail." (Calomiris & Schweikart, 1991, p. 817).

fewer large cities, and little manufacturing except in border areas. Slave owners controlled politics and economics, although about 70% of Southern whites owned no slaves and usually were engaged in subsistence agriculture.[32]

Political Change in America

The period after the Civil War, called the *Reconstruction Era* (1865–1877), was a period of political turmoil; President Lincoln was assassinated in 1865, followed in 1866 by a full-scale political war between Democrats and the radical Republicans.

> *Troubled by corruption, Americans were even more shocked by postwar violence. The fires of economic and social transformation kindled conflicts over political power in the South and land in the West, while fierce clashes also broke out between labor and capital—including the first nationwide strikes—and among laborers themselves, especially those of different racial, ethnic, and religious backgrounds. (Edwards, 2006)*

The Civil War (Figure 16) was followed by the *Gilded Age* (ca. 1870–1900), an era of enormous growth, especially in the north and west United States, attracting millions of émigrés from Europe.

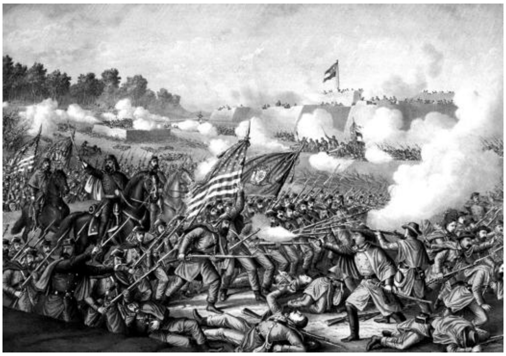

Figure 16: Battle of Williamsburg—Gen. Hancock's charge, May 5, 1862.

Source: Library of Congress, http://www.loc.gov/rr/program/bib/ourdocs/ CivilWarRecon.html.

> *Steamships ferried wheat, cigarettes, rubber, missionaries, immigrants, and tourists all over the globe. Millions of people said farewell to friends and kin in China, Russia, Mexico, Italy, and many other countries to seek their fortunes in America. Within the United States, individuals left the eastern seaboard for the frontier, the countryside for the towns, the towns for the cities, and together they made up mass migrations."* (Ibid.)

From 1865 to 1890, 10 million north-western Europeans (e.g., English, Irish, German, Scandinavian) settled permanently into the United States. The dismal working conditions for factory employees (especially women and children) was just one of the many social problems as the United States moved into the Industrial Age. Nearly ten thousand strikes and lockouts occurred in the 1880s alone. The gap between the poor and the rich

[32] Source: Wikipedia: Events leading to the American Civil War. (Accessed October 2014)

widened. The young American nation was rapidly expanding its economy into new areas, especially heavy industry like factories, railroads, and coal mining.

Along with these advances and an expanding national railroad network, the rise of the corporation surged during this time period and propelled the Gilded Age's prosperity. Whether considered as "captains of industry" or as "robber barons," corporate tycoons acquired overwhelming and extreme wealth as they secured the United States as a world industrial power. By 1900 the process of economic concentration had extended into most branches of industry. A few large corporations, called trusts, dominated in steel, oil, sugar, meat, and farm machinery. And as "Bosses of the Senate," these captains of industry and robber barons influenced American politics (Figure 17).

Figure 17: The Bosses of the Senate

Source: https://www.senate.gov/artandhistory/art/artifact/Ga_Cartoon/Ga_cartoon_38_00392.htm. Cartoon by Joseph Keppler.

The United States became a world leader in applied technology. From 1860 to 1890, 500,000 patents were issued for new inventions—over ten times the number issued in the previous seventy years.

The Gilded Age was a period of inventors and inventions, of entrepreneurs and raw capitalism, of monopolies and conglomerates. It was the time where living circumstances, working conditions, individual communication, and individual transportation changed radically. There were changes from horse-drawn carriages and tramways to fast railroad travel; from slow postal mail to instant communication by telephone and telegraph; and from gas lamps and oil-fuelled candles to electric lamps in streets, factories, and homes.

The French Third République and "La Belle Époque"

In France the fourth quarter of the nineteenth century was characterized by optimism, relative peace at home and in Europe, new technologies, and scientific discoveries. It was shaped by many political, social, and technical changes that had taken place in the preceding decades. It may have started with the storming of the Paris Bastille in 1789. An event that was the beginning of a period of turmoil, even terror, in which the basic structure of society changed. And after the *French Revolution* came the *Napoleonic Wars*, followed by the periods with restored Bourbon monarchy, and the *1848 Revolution*. France had changed from the structure of the Ancien Régime (with Royalty, Church and Nobility in power), into a centralized state, with still the remnants of the Monarchy, Church and Nobility in power. [33]

Political change in France

The *Second Empire*, the imperial Bonapartist regime of Napoleon III from 1852–1870, had given way to the *Third Republic*. After the disastrous outcome of the war on Prussia culminating in the lost *Battle of Sedan* (September 1, 1870), at the end of the battle, Napoleon III surrendered his sword to Otto von Bismarck, the German chancellor who accompanied the Prussian general Helmut von Moltke[34] (Figure 18). Next the Prussian army sieged Paris and captured the city in January 1871. For the French a dramatic experience as Paris was the

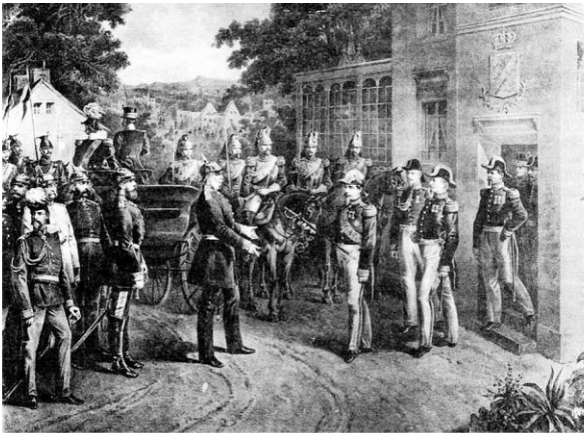

Figure 18: Battle of Sedan, 1870.

After the battle Napoleon III surrendered his sword to Otto von Bismarck, the German chancellor who accompanied the Prussian general Helmut von Moltke.

Source: Wikipedia Commons, Das Wissen des 20.Jahrhunderts, Verlag für Wissen und Bildung, 1961, Rheda Bd. 1 S.908. Author: Hartwich.

[33] A more detailed analysis is made in another case study: B.J.G. van der Kooij:*The invention of the Communication Engine.* (2015)

[34] Consequently, Napoleon III went into exile, first in Germany, later to England, before he died on January 9, 1873.

head and heart of France. The regions of Alsace-Lorraine were confiscated by the Prussians. The political outcome was twofold: one took place in the German States, the other in France itself.

The *German Empire* was proclaimed (January 18, 1871) as the kingdom of Bavaria, the kingdom of Württemberg, and the kingdom of Saxony, the states of Baden and Hesse, and the free cities of Hamburg and Bremen were unified within the *North German Confederation*.

The *French Third Republic* started with revolutionary government. Early 1871 Paris was in uproar as a civil war raged between the "communards" and the national government, ending with the election of the *Paris Commune*. That did not end the civil conflicts, however, and the "Bloody Week" (May 21–May 28) took thousands of lives on the barricades in the city (Figure 19). Karl Marx wrote about it:

> *The civilization and justice of bourgeois order comes out in its lurid light whenever the slaves and drudges of that order rise against their masters. Then this civilization and justice stand forth as undisguised savagery and lawless revenge. Each new crisis in the class struggle between the appropriator and the producer brings out this fact more glaringly. Even the atrocities of the bourgeois in June 1848 vanish before the infamy of 1871. The self-sacrificing heroism with which the population of Paris—men, women, and children—fought for eight days after the entrance of the Versaillese, reflects as much the grandeur of their cause, as the infernal deeds of the soldiery reflect the innate spirit of that civilization, indeed, the great problem of which is how to get rid of the heaps of corpses it made after the battle was over!* (Karl Marx, 1871, "The Civil War in France"[35])

With the Bloody Week, the revolutionists lost their battle to the nationalist government. Although efforts were undertaken to restore the monarchy, the French Constitutional Laws of 1875 gave the *Third Republic* its shape and form, consisting of a Chamber of Deputies and a Senate forming the legislature, and a president serving as the head of state. From a political point of view, the Third Republic was the

Figure 19: A street in Paris in May 1871.

Source: Wikipedia Commons, Maximilien Luce.

[35] The ideas behind the Paris Commune stimulated many scholars of that time (Karl Marx, Friedrich Engels, Mikhail Bakunin, and later, Vladimir Lenin). It was Karl Marx who in 1871 wrote a pamphlet "The Civil War in France," addressing the working class of the world.

beginning of the French parliamentary democracy. The old powers (Royalty and Nobility) now lost their dominance. This change into a more democratic political structure was supported by the proliferation of politicized newspapers. The circulation of the daily press in Paris went from 1 million in 1870 to 5 million in 1910.

The colonialism that all the great European powers undertook in those days, also gave France a boost after 1870 to acquire most of the French colonial possessions (Far East, North Africa, South Pacific). The French had their reasons, as expressed by the French Minister of Public Instruction and Fine Arts Jules Francois Ferry (1832–1893) in 1884:

> *"Gentlemen, these are considerations that merit the full attention of patriots. The conditions of naval warfare have greatly changed…At present, as you know, a warship, however perfect its design, cannot carry more than two weeks' supply of coal; and a vessel without coal is a wreck on the high seas, abandoned to the first occupier. Hence the need to have places of supply, shelters, ports for defense and provisioning…And that is why we needed Tunisia; that is why we needed Saigon and Indochina; that is why we need Madagascar…and why we shall never leave them!…Gentlemen, in Europe such as it is today, in this competition of the many rivals we see rising up around us, some by military or naval improvements, others by the prodigious development of a constantly growing population; in a Europe, or rather in a universe thus constituted, a policy of withdrawal or abstention is simply the high road to decadence! In our time nations are great only through the activity they deploy; it is not by spreading the peaceable light of their institutions…that they are great, in the present day."*[36]

Social change in France

From a social point of view, France changed from a rural nation dominated by the peasant farmer in the eighteenth century, to a centralized national unity in the nineteenth century. After the turmoil of the first half of the nineteenth century, people in the countryside became more and more, —obviously depending on the specific region—confronted with industrialization, railroads and steam locomotives, and improved road infrastructure. Those were the times characterized by the backwardness of rural areas, caused by beliefs and attachments to superstitions, and by the lack of education. But also the lack of integration by a common metric system and currency, physical isolation by lack of transportation infrastructure, resistance to engage formal relations with the State and

[36] Source: Quote from Jules François Camille Ferry, "Speech before the French Chamber of Deputies, March 28, 1884," in *Discours et Opinions de Jules Ferry*, ed. Paul Robiquet (Paris: Armand Colin & Cie., 1897), pp. 199–201, 210–11, 215–18. Translated by Ruth Kleinman in Brooklyn College Core Four Sourcebook; http://www.fordham.edu/HALSALL/MOD/1884ferry.asp. (Accessed November 2014)

tendency to avoid formal justice and the diversity of languages and dialects, among others. That changed with the urbanization at the end of the nineteenth century[37]:

> *Education, physical integration (by roads and railways), the market expansion, and military service were the "forces of the modernization" and were instrumental to blur the differences among rural and urban areas, bringing "alternative values and hierarchies and commitments to other bodies than the local group." Also migration (from several causes, including seasonal migration) generates a flood of peasants to these villages and big cities.*[38]

In addition to the countryside, city life also changed. Take its capital Paris. In the middle of the nineteenth century, Paris was overcrowded, dark, dangerous, and unhealthy. With a high population density and continuous traffic congestion, it was a breeding place for discontent and revolutionary thought. After the 1848 Revolution, and the coup d'état in 1851, King Louis Philippe had been replaced with Emperor Napoleon III. Under his reign Paris was massively renovated by Georges-Eugène Haussmann between 1853 and 1870. This resulted in a network of the "grand Haussmannian Boulevards" and the typical Haussmann apartment buildings. That was above the ground, but underground the boulevards the infrastructure had also changed. Networks of tunnels for water supply, sewers, and a piping system for gas distribution were created. Gas increasingly was used for street, public, and residential lighting and heating. Almost all the new residential buildings of Paris had gaslights in the courtyards and stairways; the monuments and public buildings of Paris, the arcades of the Rue de Rivoli, and the squares, boulevards and streets were illuminated at night by gaslights. For the first time, Paris was the "City of Light" ("La Ville Lumière").[39]

As the train was becoming increasingly important for the transportation of goods and people to the city, the Gare de Lyon and the Gare du Nord were renovated to make them monumental gateways to the city. And after the 1860 annexation of the surrounding villages, doubling the surface of the city and creating the "arrondissements," Paris had 1.6 million inhabitants. After the early appearance of the "Arcades" (the first premises that had large stocks of goods on the premises) in the 1820s, Paris got its "Grands Magasins": from the early "Au Bon Marche" (1838) (Figure 20) and "Printemps" (1895) to the "Galeries Lafayette" (1895). It stimulated consumerism from a numerous new kind of customer: the middle and the

[37] For more detail: (Weber, 1976), (Margadant, 1979), (Berenson, 1981)
[38] Quote from: Katherine Aguirre Tobón in *Peasants into Frenchman: The Modernization of Rural France 1879-1914* by Eugene Weber.
[39] Paris had been adapting gaslight on a large scale in the mid-nineteenth century.

working class—not only working man, but also working woman.

> *The department store was pre-eminently the "world of women," where women were encouraged to find their life's meaning in conspicuous consumption and where they increasingly found a role in selling. Thus, the department store played a highly significant role in the evolution both of contemporary society and of woman's place in that society.* (McBride, 1978, p. 664)

Figure 20: Advertisement poster for "Au Bon Marche" (1896).

Source: J. L. Goffart, lithographe, Bruxelles (1896). Herman Richir (Belgian, 1866–1942).

This all had a profound influence on *social change*. With industrialization and urbanization, for the private citizen, for the first time the living space became distinguished from the place of work. The men went to work at the factories, and the women tended house and children. And not much later, they started working in outside jobs, too. Like the jobs in the department stores.

Technical change in France

As we will see in the later chapters in more detail, technical changes had their influence on society and their economies. The first Industrial Revolution, stimulated by the development of the steam engine, had also—although with a different pace—taken place in France. And the second Industrial Revolution, stimulated by the development of electricity, would do the same.

As France did not possess as large and accessible natural supplies of coal and iron ore as countries like Great Britain, Germany, or Belgium, the industrialization took place in a slightly different form:

> *Industrialisation set in hesitantly, not least boosted by the measures introduced by the State after the 1789 revolution. The introduction of the "code civil" occurred simultaneously with the abolition of the old guild restrictions and internal customs tariffs. The currency was stabilised and the Bank of France created. The state was involved in the construction of roads and canals. But France remained primarily an agricultural country until way into the 20th century. Large new factory areas were concentrated in specific regions, above all in the north and east of the country. By 1830 there were three established cotton mill centres: around Rouen in Normandy, between Lille and Roubaix in the North, and the most modern in Alsace. In Mühlhausen this led to a highly efficient engineering*

industry which went on to export spinning machines and cotton looms to the whole of Europe.[40]

Figure 21: Japanese Satsuma pavilion at the Exposition Universelle in Paris (1867).

Source: Wikimedia Commons.

As this is not the place to cover that development in detail, we will highlight only some aspects, like the phenomenon of the "great exhibitions". One has to realize this was the time of colonialism, of international trade opening up the world beyond Europe and America. The growing activities in the British Empire and the French Empire did the Mid-East, Far East, and Africa become interesting for large groups in society (politically, socially, and economically). This interest was recognizable at the special attention they got at the exhibitions that took place: the exhibitions at the Crystal Palace (London, 1851) (Figure 12) and the dedicated pavilions of countries like Japan (Paris, 1867) (Figure 21).

Figure 22: The Eiffel Tower at the entrance to the 1889 World Expo.

Source: Wikemedia Commons, by Georges Garen.

But the World Fairs, as they were also called, were also to show what progress was made, both in cultural terms and industrial terms. As can be recognized in the *Exposition Universelle [d'art et d'industrie] de 1867* and the several later Expositions Universelle (1878, 1889, 1900), the display of all that novelty in fine arts and new machinery, from electric lights to telephones and telegraphs, fascinated the visitors.

Among the many inventions on display was the Alexander Graham Bell telephone. Electric arc lighting had been installed all along the Avenue de l'Opera and the Place de l'Opera, and in June, a switch was thrown and the area was lit by electric

[40] Source: http://www.erih.net/industrial-history/france.html. (Accessed November 2014)

Yablochkov arc lamps, powered by Zénobe Gramme dynamos. Thomas Edison had on display a megaphone and phonograph.[41]

The 1889 exhibition, which featured the Eiffel Tower as an entrance arch (Figure 22), had a "Galerie des Machines," where all those new electric machines (dynamos, motors) were shown. The exhibition, which heralded the second Industrial Revolution, flabbergasted the millions of visitors.

Figure 23: Moulin Rouge (1891).

Lithography by Toulouse Lautrec.

La Belle Époque

As the political and social turmoil more or less ebbed away over the years—except for the Dreyfuss Affair and the odd assassination of President Carnot in 1894—the celebrations related to the 1889 World Fair created an atmosphere of optimism. It was the *fin de siècle* for the French culture and the time of the emerging haute couture. French cuisine was under the influence of the legendary chef George Escoffier (1846–1935) at the hotel Savoy in Paris. The cabaret club Moulin Rouge (1889) in Montmartre, Paris, became known for extravagant shows, inspired by the circus, and the famous dance style "cancan." The posters made by Toulouse Lautrec for the performances in the Moulin Rouge became famous (Figure 23). The same was the case for the painting by Pierre Auguste Renoir *Bal du Moulin de la Galette*, located in Montmartre, which expressed so clearly the spirit of the time (Figure 24).

Figure 24: Bal du Moulin de la Galette.

Painting by Pierre Auguste Renoir (1876).

Source: Wikimedia Commons.

[41] Source: Wikipedia: http://en.wikipedia.org/wiki/Exposition_Universelle_(1878). (Accessed November 2014)

Those who were able to benefit from the prosperity of the era were drawn towards new forms of light entertainment during the Belle Époque, and the Parisian bourgeoisie, or the successful industrialists called nouveau-riches, became increasingly influenced by the habits and fads of the city's elite social class, known popularly as Tout-Paris ("all of Paris," or "everyone in Paris"). The Casino de Paris opened in 1890. For Paris's less affluent public, entertainment was provided by cabarets, bistros and music halls. [42]

The famous luxury night express train *Le Train Blue*, created in 1883 by the *Compagnie International des Wagons-Lits*, stopped at the Gare du Nord. It brought the English upper society trying to escape the British winter to the warm Cote d'Azur on the French Riviera.

Summary

In the preceding we painted in large, descriptive brushstrokes the spirit of time that created the context for the technical changes to come. Not with any pretence to be complete, it paints a picture of the latter half of the

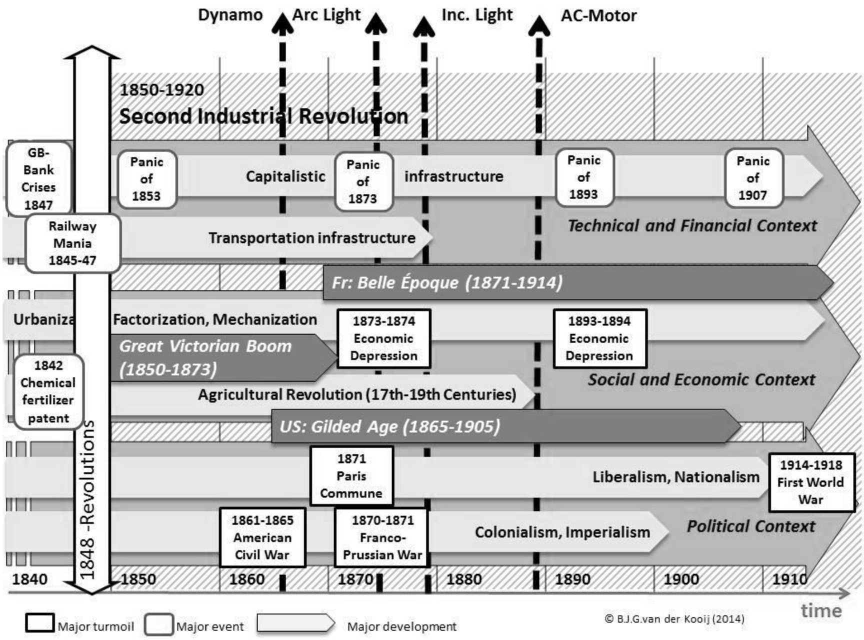

Figure 25: The context for the development of the electric light.

Source: Figure created by author.

[42] Source: Wikipedia: http://en.wikipedia.org/wiki/Belle_%C3%89poque. (Accessed November 2014)

nineteenth century, a period in time that created a technical and financial context, a social and economic context, and the relatively limited "madness of times," with its own wars and conflicts and turmoil in economies with booms, crises, and depressions (Figure 25).

It was the time of emerging capitalism, the time with the manias and the panics, and the time of the Industrial Revolutions that created the transportation infrastructures and the engines that powered the transport of people and goods. It was also a time where the economies of the Western world grew, creating the Victorian boom that heralded the Belle Époque and the Gilded Age. But It was also a period of turmoil, where the middle class and the working class demanded their rights—sometimes in quite dramatic events like the Paris Commune, and sometimes with less violence, but with similar results (England, The Netherlands). It was the time of colonialism and imperialism that created massive "empires" like the British Empire. All these developments creating the broad context would be setting the stage for the development (among many others) of a completely novel phenomenon: electric light. But first it had to be understood. What was that phenomenon of "light"?

Science discovers light

Scientists wondered a long time over the question "What is the nature of light?" As light is something that is emitted, it has to be transmitted, and it has to be received. That is, the human being "seeing" the light has to interpret it. This interpretation is not only individually based (e.g., blind people, colour-blind people), but also collectively interpreted—like in ancient times when people worshipped the sun god (the sun god Ra for the Egyptians, Surya for Hinduism, Tonatiuh for the Aztec), the sun being that mysterious source of light that appeared and disappeared. That collective curiosity about the nature of light changed over time.

> [The question what is light] *To the Egyptians it asked after man's relationship to the God Ra. They sought first a moral or spiritual answer, not a mechanistic one. By contrast, we search to explain the nature of light by tracing light rays through intrical optical systems. We seek light's mathematical and physical lawfulness.* (Zajonc, 1995, p. 38)

That scientific curiosity had started to play an important role in the period before 1800. Much happened that created the foundations for later developments. However, as this is not the place to discuss science's general development over time (as in the "history of science"), we will limit ourselves to those scientific developments that created the "electric technologies." Basic elements in those developments were the discoveries into the phenomenon of "electricity" and its relation to light.

As we have seen,[43] many theories were created about the nature of electricity in relation to light—or the "power of lightning," as it was called in those days. Developments were based on observations and experiments by scientists and engineers trying to create an understanding of the nature of the phenomenon at hand. Much was based on the fascination about the phenomenon of electric lightning, a frightening but also a spectacular phenomenon that sparked the interest of quite a few scholars.

Nature of lightning: from static to voltaic electricity

The American Benjamin Franklin (1706–1790)—a so-called "atmospheric electrician,"—was one of those highly interested in the phenomenon of atmospheric electricity as it appeared in lightning in thunderstorms. Together with friends he was interested in the meaning of these manifestations of "the electric fire." What we call electricity nowadays, was considered to be a "fluid" in those days. Some considered it as two fluids (like the Frenchman Charles du Fay, 1698–1739), but Franklin saw it differently: "The new one-fluid conception of electricity gave Franklin an insight into many complex electric phenomena, including the condensing property of the Leyden jar, and was of course an anticipation of modern ideas on the electrical structure of matter, in which electrons, detached from atoms, comprise the 'subtile fluid'." (Schonland, 1952, pp. 376-377). He developed an electrical machine with which he could charge a conducting body. And his experiments resulted in the "lightning rod," protecting construction from thunderbolts.

Franklin became famous for bringing lightning down to earth: the *Philadelphia Experiment*. In this experiment in 1750, he proved the existence of electricity by flying a kite in a thunderstorm. The kite twine conducted the "electric fire" along the wire to a key at the bottom. Franklin wrote in a letter to his friend Mr. Peter Collins of London:

> *When rain has wet the kite twine so that it can conduct the electric fire freely, you will find it streams out plentifully from the key at the approach of your knuckle, and with this key a phial, or Leiden jar, may be charged: and from electric fire thus obtained spirits may be kindled, and all other electric experiments [may be] performed which are usually done by the help of a rubber glass globe or tube; and therefore the sameness of the electrical matter with that of lightning completely demonstrated.* (Franklin, 1751, p. 566).

So Franklin and his associates established the existence of static electricity: the "electrical fire" as it was also called. As it also could be created by friction or rubbing, it was therefore also termed "frictional

[43] See: B.J.G.van der Kooij: *The invention of the Electromotive Engine.* (2015)

electricity." But for a long time, the theories of the dual-fluid versus the single-fluid caused intense debates among scholars (Heilbron, 1979, pp. 431-448).

It took quite a while for some developments (like the "animal electricity"), but the next big step in understanding and using electricity was the creation of the voltaic battery by the Italian Allessandro Volta (1745–1827) around 1800. His creation of an electrochemical device that could create electricity—the voltaic pile—spread like wildfire in the scientific community of those days.

> *Volta reported the invention of the "electric pile" in his famous letter, dated March 20, 1800, to Sir Joseph Banks (1743–1820), president of the Royal Society, London, U.K. His report was published in the Philosophical Transactions and the Philosophical Magazine.* (Anders, 2003, p. 1061)

His discovery initiated a range of investigation into the nature of electricity. In England (Davy, Faraday, Maxwell), in France (Ampere, Arago), and in Danmark (Oersted), just to name a few, conducted experiments. Those experimenting with electricity without understanding the basic aspects of the phenomenon, observed without any doubt what many people experience in our time: the short circuit of the battery, resulting in either sparks or the red-hot glowing of the wire. In the first case, it is an electric spark that is the result of ionization of the air between two electrically charged wires. The ionized air between the nodes then acts like a conductor. In the second case, (part of) a wire is connected between the plus and minus nodes of a battery, which results in an electric current that heats up the wire abnormally high, causing it to glow. These two basic phenomena would create two different trajectories in the development of electric light: the arc light and the incandescent light. We will explore those later on.

Nature of light discovered

In the late eighteenth to early nineteenth century, many scientists were experimenting with "light," trying to understand the nature of light, its properties and characteristics. Just to mention a few of these early experimenters and their work, should illustrate the development of this part of science (Figure 26).

It was the German-born, later naturalized Englishman William Herschel (1738–1822), who discovered infrared light around 1800. Then the German Johann Wilhelm Ritter (1776–1810) discovered ultraviolet light. Both were participating in discovering the *spectrum of light* (from infrared to ultraviolet).

The Frenchman Augustin Fresnel (1788–1827) studied the wave theory of light. And the German Joseph von Fraunhofer (1787–1826), working with telescopes, discovered properties of the spectrum of light (the Fraunhofer lines are today's "absorption spectrum").

John Hershel and W. H. Fox Talbot demonstrated in 1800 that, when a substance is heated and its light passes through a spectroscope, it has its own set of characteristic bright lines of color: the "emission spectrum."

Michael Faraday noticed around 1845 that light interfered with magnetism (the "Faraday effect"). And he discovered the wave property of light, which corresponded with the visible spectrum of light but extended beyond it. This, in turn, fascinated scientists like the German Heinrich Rudolf Hertz (1857–1894), who discovered "radio waves" around 1886.

And finally, the German Wilhelm Conrad Röntgen (1845–1923) in 1895 discovered "röntgen rays."

All these efforts created an understanding of the "nature of light," resulting in today's understanding that visible light (and near-infrared light)

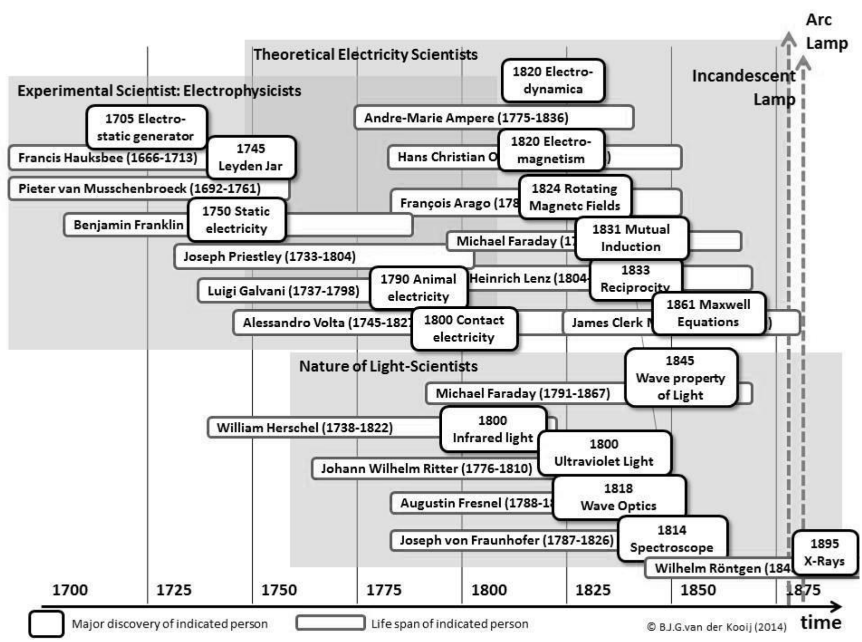

Figure 26: Scientists discovering nature of light.

Source: Figure created by author.

is related to electrons in atoms that move from one energy level to another. It is either absorbed, allowing the chemical mechanisms that underlie human vision and plant photosynthesis, or it is emitted, creating light.

Then other scientists, expanding on this body of knowledge, started working on creating "electric light." It was an important field of application, as artificial light in those days meant looking for an alternative for "oil light," "candlelight," or (later) "gaslight."

Gaslight

Till the late eighteenth century, artificial light was supplied by the candle, and wick lamps burning different lighting fuels: olive oil, beeswax, fish oil, whale oil, and similar substances. It was used on an incidental basis, as people went to bed when the sun set. Originally, after sunset evening life was a situation nearly incomprehensible for someone living in today's world (Figure 27). That changed when gas was used as fuel. It had a massive impact on daily life.

Figure 27: The reading lesson.

Source: Wikimedia Commons, Knut Ekvall.

The origin of gaslight

Gaslight needs two conditions: there has to be an inflammable gas, and it has to be ignited. So the discovery of the fact that certain gasses are inflammable was quite a basic one. That inflammable gasses existed was already known for a long time. It was described by Thomas Shirley in his *"A description of a well and earth in Lancashire taking fire by a candle approaching it"* (Shirley, 1667, p. 482).

> *About the latter end of February, 1659, returning from a journey to my house in Wigan, I was entertained with the relation of an odd spring situated in one Mr. Hawley's grounds…in that road which leads to Warrington and Chester. The people of this town did affirm, that the water of this spring did burn like oyle; into which error they suffered themselves to fall for want of due examination of the following particulars. For when I came to said spring, (being five or six in company together,) and applied a lighted candle to the surface of the water, 'tis true there was suddenly a large flame produced, which burnt vigorously…* (Matthews, 1827, p. 4)

The presence of those gasses from natural sources ("choke damp") was known to miners. Gas explosions that occurred when they went for digging coal assisted by the light of an oil lamp proved the hazardous property, as described in "*An account of the damp air in a coal-pit of Sir James Lowther, sunk within twenty yards of the sea*":

> *Under this Blackstone lies a Bed of Coal two Foot thick. When the Workmen firft prick'd the Black Stone Bed, which was on the rife Side of the Pit, it afforded very little water, contrary to what was expected; but instead thereof a vast Quantity of damp corrupted Air, which bubbled through a Quantity of Water then spread over that part of the Pit, and made a great hissing Noife; At which the Worken being somewhat surprised, held a Candle towards it, and it immediately took Fire upon the Surface of the Water and burn'd very fiercely; the Flame being about half a Yard in Diameter, and near two Yards high, which frightened the Workmen so that they took the Rope, and went up the Pit, having first extinguished the Flame, by beating it out with their Hats…*(Lowther, 1733, p. 110)

But also the gasses that resulted from brewing beer could burn, as Priestly noted during his experiments with different kinds of "air": "fixed air" (carbon dioxide), "nitrous air" (nitric oxide), "marine acid air" (hydrogen chloride), "alkaline air" (ammonia), "vitriolic air" (sulfur dioxide), "phlogisticated nitrous air" (nitrous oxide, laughing gas), and "dephlogisticated air" (oxygen). (Priestley & DFRS, 1775)

That certain gasses could burn was clear and that coal was related to the creation of those gasses also (gas as the "spirit of coal"), but the application of that property for illumination purposes was another matter. That changed at the end of the 1790s and is credited to John Murdoch, the partner of James Watt.

> *The man who first applied the inflammability of gas to the purposes of illumination, was Mr. Murdoch. This gentleman, residing at Soho, near Birmingham, that hot-bed of ingenuity and mechanical science, on occasion of the celebration of the peace of 1802, covered the works of Soho with a light and splendour that astonished and delighted all the population of the surrounding country. Mr. Murdoch had not attained to this perfection without having had many difficulties to encounter. In the year 1792, he used coal gas for lighting his house and offices, at Redruth, in Cornwall; and in 1797 he again made a similar use of it at Old Cunnock, in Ayrshire. At Soho, he constructed an apparatus which enabled him to exhibit his plan on a larger scale than any he had heretofore attempted. His experiments were then seduously continued, with the able assistance of Mr. Southern and Mr. Henry Creighton, with a view to ascertain not only the best modes of making, but also of purifying and burning gas, so as to prevent either the smell or the smoke from being offensive.* ("Outline of the History of Gas Lighting.," 1827, pp. 449-452)

It was the Englishmen William Murdoch (1754–1839), working for Watt & Boulton, makers of steam engines, who in the 1790s experimented with gas-lighting—first in his house, and later as a replacement for the oil and tallow that produced light in the Soho factory. He made in 1802, as part of the public celebrations of the Peace of Amiens, a public exhibition of his lighting by illuminating the exterior of the Soho Foundry (Luckiesh, 1920, pp. 63-79). Similar stories could be told about the discovery of inflammable gasses elsewhere (France, Germany, USA), like that of the French engineer Philippe Lebon (1767–1804) in Paris:

> *Lebon was responsible for the first public demonstration of gas lighting and heating in October 1801. He had developed what he termed a "thermolamp" in which fuel (probably wood) was heated, and the subsequent gas was relayed in pipes for lighting and heating. The purpose of the Paris display was to attract subscriptions for 200 thermolamps. The demonstrations lasted for several months, apparently attracting much attention, and some thousands of visitors are said to have attended. Nevertheless, the subscriptions were not forthcoming and the project came to nothing. Lebon himself was soon engaged in a scheme for making tar for the French navy, but before he could return to his work on gaslighting he was assassinated while engaged on engineering works connected with Napoleon's imperial coronation 1804.* (Falkus, 1982, p. 221)

Between these origins and the application on a large scale of inflammable gasses for illumination purposes, quite some developments had to take place: 1) the development on the supply side of gas: production and distribution of gas; 2) the development on the user side of gas: the manufacturing of gas lamps. For both there was a clear need in a time that only had the flame of a candle as illumination. Take the situation in Brittan at the end of the eighteenth century:

> *The disadvantages of existing illuminants were considerable. Tallow candles needed frequent snuffing if their light was not to be impaired by smoking and guttering, while the alternative wax candles were from three to four times as expensive as tallow. Oil lamps tended to smoke in draughts, regulation of the supply of oil was difficult, while the cheaper types of oil burned with an unpleasant smell. Oil lamps and candles were most inconvenient where large areas needed lighting, for then the labour involved in constant snuffing, the smoke and heat, and the dangers from sparks, were at their greatest. Much light was required by factories and workshops on winter evenings and also by shops and inns. Theatres and assembly rooms, which became common features of Georgian social life, were also large consumers. Street lighting, too, was another area where existing methods of illumination were found increasingly inadequate. For all these uses demand was growing rapidly towards the end of the eighteenth century, and*

doubtless it was these particular outlets which accounted for a good part of the overall rise in consumption of tallow and oil. (Falkus, 1982, p. 219)

The industrialization that followed the Industrial Revolution also increased the need for illumination within the factories. Originally the tallow[44] candles were overwhelmingly the major source of artificial lighting. And as many people worked for long hours, quite some quantities of oil and tallow were used: "This firm [McConell & Kennedy] burned an average 1,500 candles each night for 25 weeks in the year and consumed more than 15,000 lbs. of tallow" (Falkus, 1982, p. 219). So in today's terms, one could say that there was "a distinctive need in the marketplace," which was illustrated by the fact that a Manchester cotton spinner, George Augustus Lee, partner in the firm Phillips & Lee, wanted gas illumination in his factory. He suggested Watt & Boulton consider entering this new business activity and wanted to become the "leading customer."

I have intended very day since Mr Murdock's Departure to write to you upon the Subject of the new mode of lighting by inflammable gas. Is it not an object of atention for you to undertake to prepare the Retorts, Air-holders, Pipes & other Apparatus with Directions and Drawings for erecting them, which could afford you a profit and him a Recompence for the Invention? I am convinced it will be as generally introduced as your engines here so that you will have the same pre-eminence and preferment. In case you think it eligible to undertake it you will please to prepare the requisite apparatus for our Mills as early as possible. Other modes might be devised of obtaining some Recompence for Mr Murdock but none so eligible & reputable. (Falkus, 1982, p. 223)

This would become the development path of the local gas system, where the production of gas was done by the consumer directly. It was the approach Watt & Boulton followed. The other development path was creating companies that would produce the gas and then distribute it through a (small) local network.

The problems were largely technical. The basis of gas production lay in four processes: the heating of coal in retorts (usually made of cast iron in this period) resulting in the release of gases and liquids as a vapour, and the production of coke; the condensation of the vapour to remove as much tar, ammonia, and other unwanted substances as possible; the purification of the remaining gases to remove further impurities, the most troublesome being the evil-smelling hydrogen sulphide; and the storage of gas prior to distribution to the burners. At each step small producers encountered difficulties. (Falkus, 1982, p. 229)

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44 Tallow is a rendered form of beef or mutton fat, processed from suet. It is solid at room temperature.

Supplying individual factories with a system for gaslight was one thing; creating companies that supplied the gas from central stations and distributed it through the streets to their final destination (public buildings, theatres, streetlights, houses, shops, and factories) was a completely different affair.

The centralized production and distribution of gas

Both Murdoch's and LeBon's experiments had drawn the attention, not only of the public, but also of more entrepreneurial spectators, like Frederick Albert Winsor (1763–1830), a German inventor and pioneer of gas-lighting in England and France:

> *Initially his plan was to raise subscriptions for a "society" to manufacture the "Imperial Patent Light Stove", an evident imitation of the thermolamp. A vaguely-worded patent had been taken out by Winsor in 1804—the first British gaslighting patent—and Winsor obviously hoped to use this as the basis of his "lucrative national concern". Sometime toward the end of 1806 Winsor's plans changed. He moved his lectures and demonstrations from the Lyceum to a house in Pall Mall and attempted now to promote a "National Light and Heat Company" which would have a monopoly to provide "Streets, Squares and Houses with Gaseous Lights by means of conducting tubes under Ground from distant Furnaces". Winsor hoped "to introduce these pure and salutory Lights in all the streets and houses throughout the Realm and Colonies.* (Falkus, 1982, p. 226)

In 1804 Winsor got his British patent №. 2,764 for street lighting using gas. In 1807 he had attracted enough capital for his new venture: the National Light and Heat Company. It was quite a speculative situation, where several London water companies and dozens of gas companies—like the National Heat and Light Company—were launched. An investment frenzy is illustrated by the September 1807 letter from Lady Bessborough to Lord Granville Leveson Gower:

> *There is no other subject thought of or talk'd of…Is it the seizure of Zealand? No! The investing Copenhagen? No! The Invasion? Oh no! War with Russia? Nothing like it. America? Stilless. What can occasion such a ferment in every house, in every street, in every shop, in every Garret about London? It is the Light and Heat Company. It is Mr Winsor, and his Lecture, and his gas, and his patent, and his shares—these famous shares which are to make the fortune of all who hold them, and probably will involve half England in ruin, me among the rest, and prove a second South Sea Scheme. Yet it promises fair if it did not promise too much—six thousand a year for every seven guinea seems more than can be possible; but were it hundreds instead of thousands it is immense. 17 thousand shares have been sold within these ten days: they were first a guinea,*

> *then 3, five, seven; they will be twenty, fifty, a hundred, for there is scarcely means of passing thro' Pall Mall for the crowds of carriages, and people on foot and Horseback. Ld. Anson has 100, the D of Athol 200, the Royal family 200, Ld Chol[mondel]y 20—everybody some and I five.* (Falkus, 1982, p. 228)

All those dynamics on the financial markets in the 1807s contributed to the 1808-financial crises.

> *The boom on which the company was floated was in large measure initiated and fanned by the prospects of speculative gain from import substitution as a consequence of the continental blockade. The gas company, with tallow prices rising rapidly as imports were curtailed, was in some ways typical of this speculation, but it should be stressed that the company was one of the few to survive the subsequent financial crisis of 1808.* (Falkus, 1982, p. 227)

What was needed was an Act of Parliament, but that took some effort as there was some opposition: "Opposition at the committee came principally from James Watt Jr., who apparently feared that, just at a time when the Soho gas business was promising so much, the new company would have a monopoly of the manufacture and supply of gas apparatus" (Ibidem). It resulted in quite some concession, and the monopoly became quite restricted (in area and in equipment). Even after that it took another year and a half before the company—now called the London and Westminster Chartered Gas-Light and Coke Company—came into existence.

> *The year 1812 saw the foundation of the first gas company, the London Gas-light and Coke Company, established by royal charter. Four years later came the earliest provincial companies, in Preston and Liverpool, and there followed a rapid extension of the industry to most of the major towns by the mid-1820s. The companies' business usually involved an initial contract with the local authorities to light public lamps (often a cheap supply of gas to public lamps was made a condition upon a company for the privilege of disturbing paving in order to lay their mains) and, with this demand secured, the company would supply to private consumers. The "lighting of a town" by gas was thus largely synonymous with the spread of the gas industry…In 1820 no town in the United Kingdom with a population greater than 50,000 was without a gas company, and by 1826 the industry had made such rapid strides that very few towns of more than 10,000 were not served…At first, as mentioned earlier, demand for gas came primarily from public lighting authorities and business establishments, but by the 1840's its use was growing in middle- and upper-class homes. Consumption was fostered also by considerable improvements in the quality of gas and by better lamps, burners, and methods of ventilation. More important, however, was the adoption of gas meters which by the mid-1830's had come into general use (although even in 1846 a few companies still charged by the period of time for which gas was supplied)…*(Falkus, 1967, pp. 494-495, 497, 500-501)

Building networks of pipes from a central point to the consumers was a major task. Between 1812 and 1820, the Gas-Light and Coke Company built the world's first urban gas network in London: both the gas factories (Figure 28) and the distribution systems. They were, with the water-distribution networks, the first large-scale infrastructures related to the technological innovations that accompanied them. Soon they would be followed by other large-scale technical systems: the railway networks and the electricity networks.

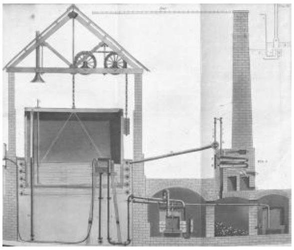

Figure 28: The first London gasworks, 1814.

Source: Plate from Accum's A Practical Treatise on Gas Light (1815), Wikimedia Commons.

> *The growing presence of water companies piping water under streets to homes, such as the new West Middlesex Waterworks Company and the recently expanded New River Company, presented Winsor with a legal model, as well as one way to imagine the distribution of gas—via pipes running under the streets.* (Tomory, 2011, p. 80)

Developing the network took time, money, and patience, as the Gas-Light and Coke Company (GLCC) owned the complete network: from gasworks to the gas burners (lamps).

The early application of gas lamps

The first ranges of application for the gas-light system were threefold: public buildings, streetlights, and private housing/shops. Each had its own problems.

> *GLCC had three sorts of customers. The first were public buildings, such as the Parliament buildings and theatres, which were relatively lucrative and unproblematic, generally paying their bills and keeping to their lighting schedule. The second were streetlighting authorities. The responsibility for lighting streets in London at this time lay with a messy patchwork of civil parishes, special jurisdictions like Parliament, road and park trusts, and assorted other entities, each of which would typically sign contracts with companies to keep their oil lamps lit. GLCC became another contractor for streetlighting, although it had been forced to accept terms that were not entirely favorable; in exchange for granting the company special rights, such as the right to remove pavement to install pipes, Parliament had demanded concessions, including a mandate to provide streetlighting for interested local authorities at lower rates than the cost of oil lamps…The third sort of customers were homes and small shops. Although these did create profits for GLCC, these customers proved the most difficult to control.* (Tomory, 2011, p. 82)

The development of the network (Figure 29) was not without financial and technical problems. The financial problems led to dissatisfied shareholders, managerial problems resulting in reshuffling the management structure (Frederick Winsor left the company in 1815), and the need for additional cash injections.

Some of the public buildings that were adapted to gaslight were the Westminster Hall and St. John's Church. Its implementation was quite successful but for the fact that the production of gas faced technical problems. The application of gaslight for street lighting was another story. The first project—Norton Folgate—proved to be a disaster.

> *GLCC's first contract for street lighting, signed on 7 May 1813, was with a tiny administrative unit in the metropolis called Norton Folgate, and it bound the company to commence providing gaslight on 29 September of the same year—a wildly optimistic gambit on the part of the directors, given that they had not yet acquired land in the area to build a plant…Consequently the plant's construction was rushed and chaotic; no attempt was made at competitive bidding for large orders of parts, and as a result expenses soon ran out of control…When 29 September arrived, the apparatus was nowhere near ready and the company had no choice but to provide oil lamps for Norton Folgate at the company's expense.* (Tomory, 2011, pp. 83-84)

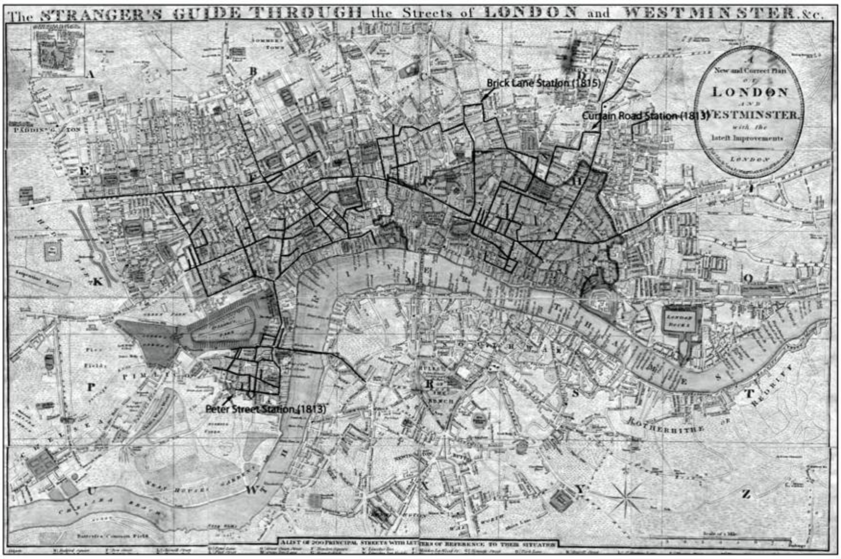

Figure 29: Map of the GLCC network of gas distribution in London (1814).

Source: Tomory, 2011, p. 90.

The application of gaslight in homes and shops also proved to be quite troublesome for GLCC.

> *Gas users tended to view the product as a replacement for candles and oil lamps, one which could be used whenever desired, at any time of day or night. GLCC, by contrast, wanted to restrict the times at which users could consume gas in order not to exceed the company's generating capacity. GLCC's efforts to routinize and stabilize its network—a normal part of the development of large networks—also involved working with a group of mediators who were not initially under GLCC's control. Because the company was prevented by law from installing lamps and pipes in homes, it relied on outside contractors called "fitters up." Since these fitters had no long-term relationship with the customers, their installations were often very poor, leaving the company to placate irate customers and repair their work.* (Tomory, 2011, p. 78)

It took a while, and coping with a broad range of technical and managerial problems, before the company proved to be successful. But by 1820 the company was operating successfully.

> *In mid-1814, it had four paying customers and £180 in annual revenues; by 1816, it supplied gas for the approximately 8,600 lamps of its 2,400 customers, with revenues of £35,713; and by 1820, its 122 miles of mains were supplying gas to about 30,000 lamps and its revenues had reached £101,785…GLCC's change in management in 1814 helped make GLCC a viable company that, by 1820, had successfully built a gas network in parts of London.* (Tomory, 2011, p. 101)

Gas-Lighting everywhere

Not only in England had gas-lighting become a hot item. Everywhere the public interest in the new phenomenon was great—not that its introduction into society was without problems, though:

> *Although gas-lighting was born in England it soon began to receive attention elsewhere. In 1815 the first attempt to provide a gas-works in America was made in Philadelphia; but progress was slow, with the result that Baltimore and New York led in the erection of gas-works. There are on record many protests against proposals which meant progress in lighting. These are amusing now, but they indicate the inertia of the people in such matters. When*

Figure 30: Gas lamp ignited by the lamplighter.

Source: http://partleton.co.uk/Benjamin1839Page2.htm

> *Bollman was projecting a plan for lighting Philadelphia by means of piped gas, a group of prominent citizens submitted a protest in 1833 which aimed to show that the consequences of the use of gas were appalling. But this protest failed and in 1835 a gas-plant was founded in Philadelphia.* (Luckiesh, 1920, p. 98)

Soon after the "factory and mill lighting market" erupted by the 1810s, it was followed by the "street and domestic lighting market." This created great anxiety; people were flabbergasted. The candle business, lamp petrol, and whale oil business were going to collapse. But the profession of the candle lighter blossomed (Figure 30).

People were amazed but also concerned, as depicted in the cartoon in Figure 31. (Female figure on right in cartoon: *"If this light is not put a stop to—we must give up our business. We may as well shut up shop."*) Indoor lighting was dominant, but it also created more safety in the streets when gas lamps were installed as streetlights (male figure on right in cartoon: *"True, my dear: not a dark corner to be got for love or money."*). A few decades later, most towns in Britain were lit by gas, and most had their own gasworks, industrial plants for the production of flammable gas. In 1820 Paris adopted gas street lighting.

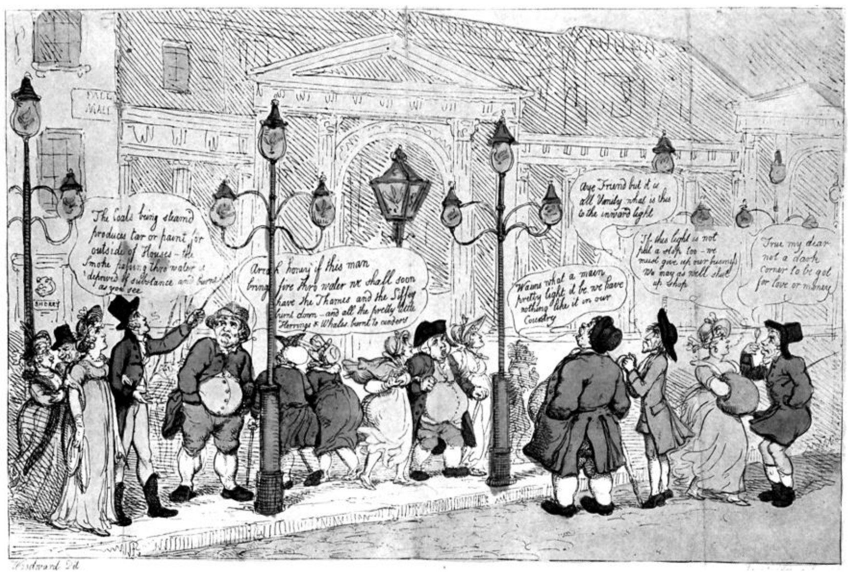

Figure 31: "A Peep at the Gas-lights in Pall Mall."

A humorous caricature of reactions to the installation of the new invention of gas-burning street lighting on Pall-Mall, London.

Source: Wikimedia Commons, Engraved by Rowlandson, 1809 (after a drawing by Woodward).

In 1859 gas-lighting was to be found all over Britain. Over a thousand gasworks had sprung up to meet the demand for the new fuel. Between 1865 and 1885, there was a boom in investment in gas, which reduced its cost even further. By the end of the century, gas-lighting was found in most shops, houses, factories, and schools throughout Britain and Europe. Depending on the local circumstances (like the availability of coal or the scarcity of wood), the distillation of gas was realized in gas factories. So soon these factories to manufacture gas from coal (or wood) were established all over Europe, each with a different local network for the distribution of gas. First it occurred in the bigger cities, like Amsterdam and Rotterdam (1822), Berlin, Bern, Brussels, and so on. Then it spread to the midsize cities all over the world: Manchester and Birmingham, Leipzig and Dortmund, and so on.

Figure 32: Gas factory at the Bleeklaan/Groninger straatweg, Leeuwarden, the Netherlands.

Source: www.historischcentrum leeuwarden.nl.

Many of these factories were the result of the activities of the *Imperial Continental Gas Association*, a British company operating across Europe, created in 1824. They established gas factories in Hannover (1825), Berlin (1825), Rotterdam (1827), Amsterdam (1834), Haarlem (1836), and Vienna (1840s). Other English companies also operated on the continent and created "gas utilities," like in the Dutch cities of Utrecht, Arnhem, and Leeuwarden. It was in this last city in the north of Holland where, in 1845, the Englishman John Bryan started the first gas factory (Figure 32) (Kooij, 2010; Visscher, 2013).[45] The pattern of urban spreading of the use of gaslight was everywhere quite similar. Take the development in the Netherlands:

> *In those large cities gas was a immediate success. And therefore smaller places almost all followed. Between 1856 and 1870 81 gas factories were founded, most by private entrepreneurs. In the largest cities the Municipal Councils tried to take over these profit generating factories. The early adopters were keepers of luxury shops (clothes, wine, chocolate), owners of hotels and restaurants, the municipalities itself (public lightning and public buildings), and middle sized factories and workshops where gas machines were used (bread, tobacco, coffee and tea). Individual consumption by private persons started very slowly. Around*

[45] Personal note: The author lived in his youth in Leeuwarden, the Netherlands, passing the gas factory when cycling to school in the 1960s.

1880 members of the elite started to substitute their oil lamps by gas lamps. The lower strata followed after 1900. (Kooij, 2010, p. 6)

To produce the gas, numerous utility companies were created. First were founded small ones, privately owned, like the *Societe de Gaz de Friesland,* later owning the aforementioned gas factory in Leeuwarden. In the bigger cities, bigger gas companies were created, like the example given of the *London and Westminster Chartered Gas-Light and Coke Company* in 1812. They extracted gas from coal and distributed it to the individual homes through a network of pipes bringing gas into the houses.

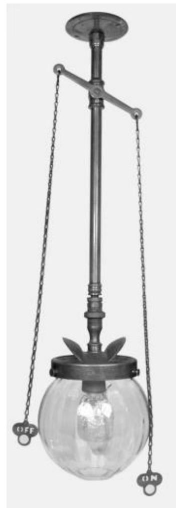

Figure 33: Incandescent gas lamp (ca. 1890s).

Source: www. lurganancestry. com/gaslight.htm.

Next there were the manufacturers of the lamps themselves. Originally gaslights were simply naked flames of varying shapes, later followed by special burners: the incandescent gaslight,[46] like the "Glühstrumpf" or "Auerlicht" (a gas mantle invented by the German Auer von Welsbach in 1882 to burn gas in order to get better light; US patent №. 438,125). Gas was adequate for house and office lighting, certainly an improvement over earlier lighting systems (Figure 33), but it was quite expensive, had some dangers involved (it was hot and explosive), and deprived the rooms of oxygen, which in public places like theatres created discomfort.

The world longed for an alternative, but in 1878 the possibility of replacing gas with electricity seemed quite unlikely. Still, gas-lighting was soon to suffer severe competition from the newly invented, but much more costly, electric light. In just a couple of decades, electricity would take over the role of powering light. It would become a revolution.

The electric revolution: the Era of Light

In the mid-nineteenth century, it was becoming clear that rotative "electromotive" power was feasible. But its introduction into power-applications (more than powering the occasional ventilator, printing press, or lathe) proved to be hindered by the cumbersome and expensive battery systems that were needed.

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[46] For more on this topic, see: (Gentsch, 1896).

For the further development of "electricity," something was needed that stimulated the need for electricity, in combination with the (cheaper) creation of electricity itself. And there proved to be such an application: electric lighting. It was one medal with two sides: the *use of electricity* would be stimulated by electric-powered lamps; the *creation of electricity* for electric light would be stimulated by the electric generator.

This not only meant that scientists had to continue to understand the "nature of light" and develop the electrical lamp; it also meant that the dynamo principle had to be explored and that machines had to be created that generated electricity. A device that was to be called an "electric dynamo" later in time.

And there was light

There were those scientists that studied the nature of light (Figure 34, top). Experimenting with voltaic batteries and wires, one cannot miss the effect of creating sparks. The larger the voltage (that is, more cells in series), the larger the spark. As we will see, this was something that Humphry Davy noted and demonstrated in the early 1800s in his lectures at the Royal Institute in London. Vasilii Petrov did similar things in Russia in the same

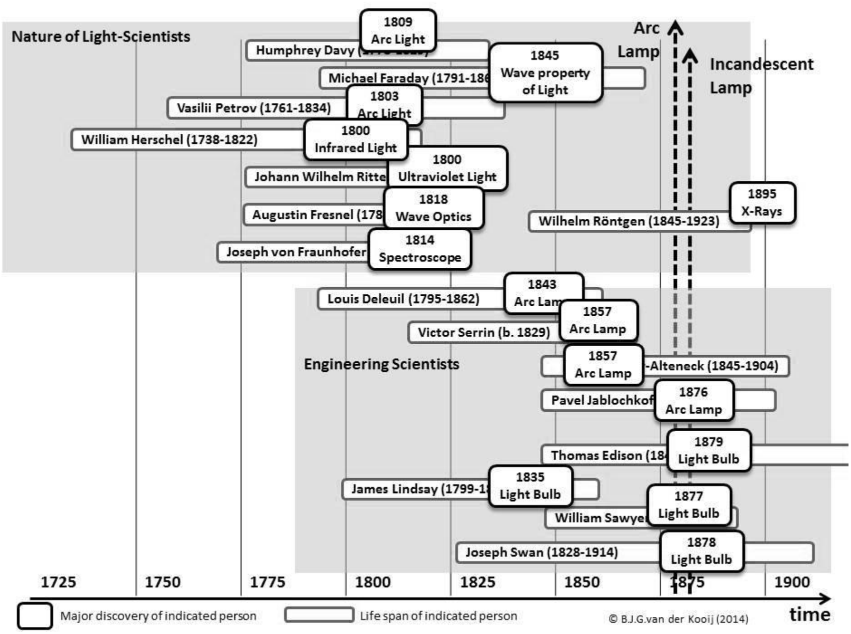


Figure 34: Engineering scientists bridging the voltaic gap by arc and filament.

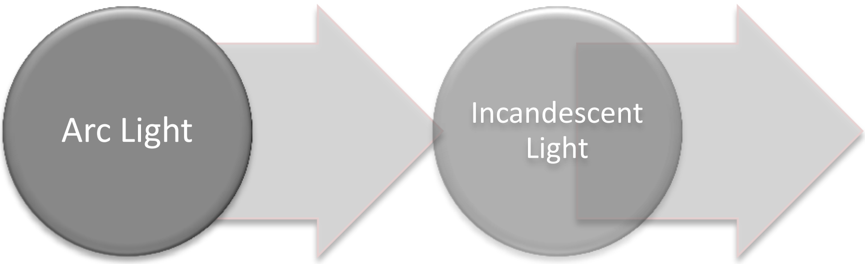
Source: Figure created by author.

period—as, undoubtedly, many more curious and inventive people did playing with the new phenomenon. People that we do not know about as their investigations disappeared in the fogs of history.

Another effect one cannot miss noting would be that a (thin) wire through which a (large) electric current passes is going to be warm, warmer, glowing, lighting, and finally burning. The warmer it gets, the more light it emits. So the trick is to have a wire at a temperature high enough to make it emit radiation in the visible part of the light spectrum without destroying it by burning. This is the idea of the incandescent lamp. Sounds simple enough, but getting from the idea to the artefact was another story.

Next to the scientists that explored the nature of light while exploring other physic phenomena in the early nineteenth century (like chemistry), a range of engineering scientists were fascinated in bridging the "voltaic gap" (Figure 34, bottom). These men were not so much interested in the nature of light (let's call that the "theory"), but in constructing mechanical artefacts that would create the light (let's call that "engineering"). As we will see in the next part of this study, they realized electric lamps that exploited the electric spark, and thus created the "arc lamp." There were also those that exploited the incandescent effect of a hot wire that bridged the voltaic gap, and they created the "incandescent lamp." Both groups, in the same period of time, created the "Era of Light." But that would take a few more decades.

The invention of the arc light



As illustrated also with the development of the DC-electromotor and the electric dynamo, the "invention" of the electric lamp was not a single act by a single person at a specific moment in time. Again, it was a range of discoveries, with several clusters of innovations. It started with discovering the phenomenon: sparks that were created when two conductors, connected to the poles of a (large) battery, would be in close contact (some mm's). These sparks emitted quite some light, not as the lightning in thunderstorms, but impressive enough to stimulate the curiosity. Could the sparks be used and converted into a source of light? Could there even be more in the relation of electricity and light?

Sparks bridging the voltaic gap

The discovery of the voltaic battery sparked (pun intended) a lot of interest among scientists. Compared with the electricity created by friction, stored in a Leyden jar, suddenly there was a new source of electricity, one that could create electricity in abundance (as it seemed in that time).

> *Following the publication of Volta's sensational results, many researchers built their own copy of Volta's pile (increasingly using Cruickshank's version) and started experiments, mainly focusing on the physiological and chemical effects of electricity…The search for the "first" continuous arc discharge is intimately related to the development of more powerful batteries because once a battery was capable of delivering enough current for a self-sustained arc, it would be hard to avoid finding arcing when performing experiments. However, to make the discovery, the experimenter also needs the skill for careful observation, interpretation, and exploration. Davy was one of such experimenters.* (Anders, 2003, p. 1062)

The spark was hard to miss by experimenters like Humphry Davy, whom we will cover further on, and the Russian Vasilii Petrov (1761–1834), professor at the Military-Medical Academy in St. Petersburg. In 1803 he experimented, like so many others, with a large voltaic pile and discovered the effects of early arc light.

> *In 1801–1803, Petrov, then a professor of the Medical-Surgical Academy in St. Petersburg, experimented with voltaic pile and constructed an arc lamp, at the same time that the English chemist, Sir Humphrey Davy, was achieving similar results (1801–1808). Neither of these two scientists knew of the work of the other.* (Vernadsky, 1969, p. 39)

His work took place in the context of the Russia of those days:

> *The news about Volta's invention traveled quickly also to St. Petersburg, capital of Russia since 1710. St. Petersburg was a new, attractive, quickly growing city within Russia. Since its foundation by Peter the Great (1672–1725) in 1703, the Russian Emperors promoted here the establishments of military, cultural, and scientific institutions that could match their counterparts in the West. Policies were put in place by Peter and later especially by Catherine II, Empress of Russia from 1762 to 1796, attracting many (West-) Europeans to the city. The Academy of Sciences and Arts was founded in St. Petersburg on decrees of Peter the Great and the Governing Senate in 1724. Among the foreign scholars, many famous artists, scientists, and engineers spent years or the rest of their life in the city.* (Anders, 2003, p. 1063)

One of these scholars was Vasilii Petrov, who had already investigated electrical phenomena at that time.

> *Electrical phenomena were very fashionable and used for the entertainment of aristocrats. Wealthy donors helped to pay for modern equipment imported from Western Europe. In the late 1790s, Petrov could acquire two large frictional electricity machines with glass disks of diameter 40 in and large copper conductors of 5-ft and 5-in (1.65 m) length…*

Petrov appeared at a meeting of the Military-Medical Academy and pleaded for the immediate acquisition of a "Galvano-Voltaic Pile" with the argument that many European natural philosophers were about to conduct experiments with large batteries. His petition was successful…

Once the large battery was completed, experiments could begin. Petrov noticed sparks at metal pieces when he interrupted the electric circuit. Using graphite electrodes, he observes the following. "If two or three charcoal pieces are placed on a glass plate or on a bench with glass legs, and if the charcoal is connected to both ends of an enormous battery using metallic but isolated conductors, and if the two pieces are brought in close distance of one to three lines [2.5–7.5 mm], then a very bright cloud of light or flame shines, burning the charcoal more or less fast, and one may illuminate a dark room as bright as one wants to. (Anders, 2003, pp. 1063-1064)

Humphry Davy (1778–1829), with Michael Faraday as his assistant, also experimented in the early 1800s with the "Volta" battery and discovered the brilliant light produced by a spark between two pieces of carbon connected to a large voltaic battery in the basement of the Royal Institute (Figure 35). He demonstrated the arc light at a presentation of the Royal Institute in 1809–1810. It was quite impressive as described by Davy in his notes:

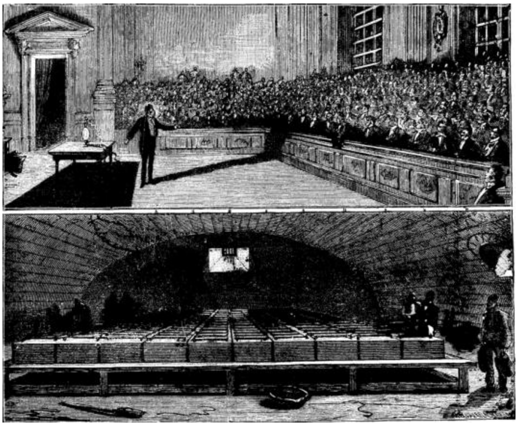


Figure 35: Sir Humphry Davy's Electric Light Experiments at the Royal Society.

Auditorium (top) and cellars with 2,000 batteries (bottom) (1810).

Source: Scientific American Supplement No. 430, New York, March 29, 1884, http://www.gutenberg.org/.

The spark [presumably the arc], the light of which was so intense as to resemble that of the sun…produced a discharge through heated air nearly three inches in length, and of a dazzling splendor. Several bodies which had not been fused before were fused by this flame…Charcoal was made to evaporate, and plumbago appeared to fuse in vacuo. Charcoal was ignited to intense whiteness by it in oxymuriatic acid, and volatilized by it, but without being decomposed…The charcoal became ignited to whiteness, and by withdrawing the points from each other, a constant discharge took place through the heated air, in a space at least *equal to four inches, producing a most brilliant ascending arch of light, broad and conical in form in the middle.* (Luckiesh, 1920, p. 113)

The experiments may have been challenging and the demonstrations a spectacle grasping the audience, but it did not result in any practical apparatus except the testing apparatus (Figure 36).

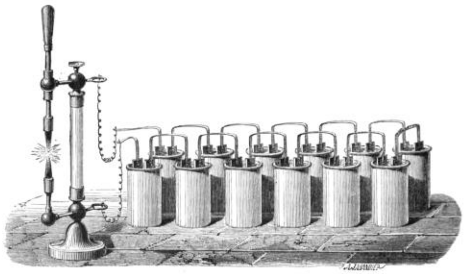


Figure 36: Experimental apparatus for producing the voltaic arc.

Source: Wikimedia Commons.

The carbon-points used by Davy were pencils of common charcoal. As such they must have wasted away rapidly, and, no regulating apparatus having been devised for adjusting the distance between them, the light must necessarily have been of short duration. In fact, it remained for 34 years a brilliant but sterile laboratory experiment. It was not until 1844 that that eminent physicist Leon Foucault replaced the soft friable charcoal by the hard compact carbon found in gas retorts; and availing himself of the newly-invented and powerful battery of Professor Bunsen he succeeded in producing a steady, continuous light. (J. Dredge, 1882, p. 25)

Early versions of the arc light

Up to the 1840s, any attempt to use the galvanic current as a practical source of light was futile because of the too-rapid consumption of the charcoal or of the incandescent wire and because the current from the chemical battery lasted for only a short time. In 1843 the Frenchman instrument maker Louis Deleuil (1795–1862) showed that he could light the Place de la Concorde in Paris with electricity by using zinc-carbon batteries (Bunsen cells) and charcoal electrodes. The electrodes were placed in a glass cylinder on the knee of a statue. He used two hundred of those Bunsen cells placed below a statue (King, 1962).

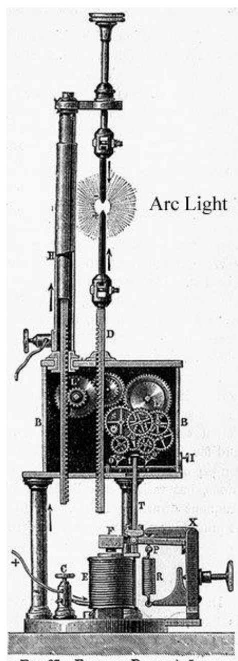


Figure 37: Foucault & Dusboscq Arc Lamp.

Source: http://www.uh.edu/ engines /epi2248.htm.

Only a few years later, the first commercial successes of the electric light occurred when the

Englishman William E. Staite and Frenchman Duboscq used their arc lights in theatrical productions (Figure 37).

> *The 19th century saw much experimentation and progress in public illumination, and after the invention of the Bunsen and the Grove cells experimenters began to examine seriously the possibility of using the new agency for this purpose. Some of the first successful attempts were made by the Parisian instrument-makers Deleuil, Archereau, and Duboscq during the 1840's…In May 1849 a ballet called "Electra," especially composed for the purpose, introduced the arc light to the public at Her Majesty's theatre in London…The ballet was an instant hit, and a command performance was given for Queen Victoria a few weeks later. A similar application appeared about the same time across the Channel, where Foucault's arc lamp was used to simulate the rising sun in Meyerbeer's latest opera, "Le Prophete."* (King, 1962, pp. 335, 337)

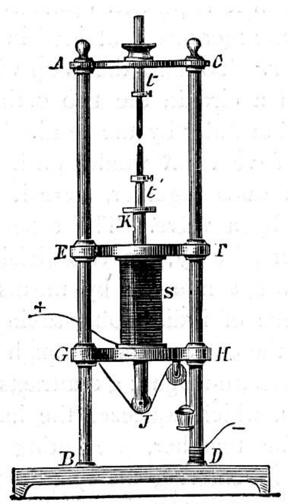


Figure 38: Archereau regulator for a carbon arc light (1849).

Source: Wikimedia Commons.

A problem with carbon rods of the arc lamp was that the rods were consumed by the spark (like in welding). A lot of effort was put into this problem, and automatic feeders—regulators, as they were called—were developed by Thomas Wright (GB-Patent №. 10,548 filed on March 10, 1845), Archereau (Figure 38), Foucoult, Dusboscq, Staite, Lacassagne, and Thiers.

> *The first person to patent an arc lamp in which the need for frequent manual adjustment was avoided was Thomas Wright, of Thames Ditton. In 1845 he had the idea of striking the arc, not between the rods, but between discs which were rotated slowly by clockwork. This open-loop control scheme maintained a constant length for one complete period of revolution…The first closed-loop regulator to appear in France was designed by M. Archereau in 1848.* (Simpson & Power, 1979, pp. 646, 647)

It was Staite who, in 1847, devised a mechanical mechanism to regulate the length of the arc, making the feeding of the carbon rods dependent on the current traversing the circuit (Figure 38). In the following years, he improved on this concept (J. Dredge, 1882, pp. 381-383). He was soon followed by others like Serrin.

> *Except for Staite's lamp, these early regulators were satisfactory only for a relatively short period of time, and so other means of regulating the carbons were*

sought. Joseph Lacassagne and Rodolphe Thiers devised a differential arc light regulator in which the current resulting from the difference of two controlling circuits fed the moving carbon at the proper speed…

Figure 39: Serrin regulator for a carbon arc light (1857).

Source: www.sparkmuseum.com.

By using a battery of 60 Bunsen cells, Lacassagne and Thiers successfully illuminated a square in their home city of Lyons in 1855, and the following year they lit up the Arc de I'Etoile and the Avenue des Champs Elysees for four hours in a vain attempt to interest Napoleon III in their invention…Then, in 1857, Victor Serrin invented a regulator based on some of the best features of that of Duboscq, and it dominated the field for two decades in France and elsewhere…Further refinements made in 1859 produced "le modele Suisse" that proved its superiority over all others. (King, 1962, pp. 340-341)

These early efforts to create functional arc lights were more or less ended around 1857–1859, when the Frenchman Victor Serrin (b. 1829) introduced his regulators for the arc light (Figure 39). During the years 1856

Table 1: Some of the British patents granted for early arc lights

Patent №.	Filed	Patentee	Description
GB 10.548	March 10, 1845	T. Wright	Electric light/Arc lamp
GB 11.449	November 12, 1846	W. E. Straite	Lighting by means of electricity/Arc lamps
GB 11.449	November 12, 1846	W. E. Straite	Lighting by means of electricity/Arc lamps
GB 11.783	July 3, 1847	W. E. Straite	Lighting by Electricity-Arc lamps
GB 2.458	October 20, 1856	J. Lacassagne; R. Thiers	Electric lamps/Differential arc lamp
GB 2.547	October 29, 1856	J. T. Way	Electric lights/Electric lamp
GB 1.033	April 13, 1857	J. B. Pascal	Electric lamps
GB 1.258	May 4, 1857	J. T. Way	Obtaining light by electricity/Electric lamps
GB 2.628	October 14, 1857	F. H. Holmes	Magnetoelectric machines/Electric lamp
GB 2.368	October 23, 1858	E.C.Shephard	Electric Lamps/ Incandescent arc Lamp
GB 653	March 15th, 1859	W.Clark	Apparatus for Regulating Electric Larnps or Lights/Arc Lamp

Source: (J. Dredge, 1882) ,Center for Research Libraries http://dds.crl.edu/loadStream.asp?iid=17444&f=8

to 1869, there was a constant succession of patents for apparatuses based on this principle.

> *In 1857, Serrin took out his first patent. His invention marks the close of the early era of electric lighting, and is the only one that maintained an existence across the interval of 17 years that elapsed before the production of the Jablochkoff candle, again called the attention of the public to the powerful means of illumination that had so long lain unused and unappreciated.* (J. Dredge, 1882, p. 395)

As indicated, many of the experiments and their resulting inventions were patented. Early British patents for arc lights are shown in Table 1.

Slow diffusion

The public enthusiasm for the arc light was enormous, understandably when all the light people knew until then had been from candles and the fire in the hearth. However, the fundamental characteristics of this technology were, next to the problem of the "wet cell" power supply, the cause that the introduction into society of the "arc light" proved to be rather slow.

> *In the decade between 1855 and 1865 a number of attempts were made to use the arc light for military operations and for public celebrations. It has been said that the arc light was tried during the naval attack on Kinburn in 1855 during the Crimean War, and in 1859 during the Italian war of independence. Joseph Henry devised an arc light in 1863 that was intended to be used for the siege of Charles-town during the Civil War, and in the same year Boston celebrated Union victories by arc-light illumination. On the occasion of the visit of Queen Isabella II of Spain to Paris in 1864, Napoleon used 11 Serrin regulators to illuminate the fountains of Versailles. Nevertheless, neither the military nor peacetime applications of the arc light took root in contemporary technology. The problems of how to make carbons for the arcs and of how to maintain the carbons at the proper distance and in the same place were more or less solved by 1860, but such endeavors were premature and could have no lasting results until an adequate source of electrical power could be found.* (King, 1962, pp. 342-343)

It was not until the first magnetoelectric dynamos were developed that the arc light became a serious source of electric light. An arc lamp that achieved widespread use in the wake of the dynamoelectric machine was that of Hefner von Alteneck—working at Siemens in Berlin—which was patented in 1873. This was the British-patent №. 2,006, filed in 1873, that was issued to Friedrich Franz Heinrich Philipp von Hefner-Alteneck (1845–1904), close assistant of Werner Siemens, for his differential lamp.

Although the voltaic arc was produced by Davy in 1810, and the experiment was repeated in numerous laboratories in this and other countries, there was, if we may take the silence of the Patent Office Records as evidence, no hasty recognition of the discovery as a practical means of illumination. The invention of the Grove battery in 1836 and the Bunsen battery in 1842, provided, however, generators of electricity that would produce a current sufficient to maintain a light for some considerable time, and almost immediately the subject of electrical illumination seems to have emerged from a state of scientific to one of practical experiment, and to have engaged the attention of one worker after another with regular succession until the year 1859…In spite of all this, however, for 12 years no improvements on existing lamps were patented, although in the meantime great steps had been taken. (J. Dredge, 1882, p. 379)

The idea for the arc light was there, the concept was proven, but the practical application was slow. All those efforts resulted in a range of different implementations. In this multitude of different systems, the following classification was made by Du Moncel in his treatise "L'Eclairage electrique" (Du Moncel, 1880):

They are divided into six categories, viz.: (1) Regulators founded on the attraction of solenoids, as those of Archereau, Gaiffe, Jaspar, and Brush; (2) those depending on movements worked by electromagnets, as the lamps of Duboscq, Foucault, Serrin, Siemens, and Rapieff; (3) those with large circular carbons, as the regulators of Wright and Reynier; (4) those depending on hydrostatic reaction, as Way's mercurial lamp; (5) those depending on the reaction of the current itself, producing mutual repulsion between the carbon poles; and (6), lastly, those with fixed carbons, such as the electric candle of Jablochkoff.

Jablochkoff's electric arc lamp (1876)

All the efforts to keep the carbon rods of the arc light at a correct distance were basically mechanical: they focused on the physical movement of one of the carbon rods. And the development trajectory of the concept of these mechanically adjusting rod systems seemed to be at a dead end. Then came the discovery of Paul Jablochkoff (1847–1894) that would become known as the "Jablochkoff candle" (1876) (Figure 40). Jablochkoff, son of a bankrupt Russian nobleman, was educated in Saint Petersburg, joined the army after graduation, and was trained in electrical engineering.

In 1871 Yablochkov finishes his military service and moves to Moscow, where finds a position of an assistant of Moscow-Kursk railway telegraph head. At that time Moscow Polytechnic Museum hosts a society of electrical experts, inventors and amateur electric engineers, who like sharing their experience in this new field. These enthusiasts of science tell Yablochkov about experiments of A. N. Lodygin, who tried to illuminate streets and dark rooms with electric lamps.

> *These brave experiments encourage Yablochkov to improve existing arc lamps. In 1874 Yablochkov quits his telegraph position and opens a workshop of physical devices in Moscow. His contemporaries describe his workshop as a "centre of courageous and sophisticated electrotechnic events, which shine with novelty and are twenty years ahead his time." In 1875, during an experiment with table salt electrolysis by means of coal electrodes, Pavel Nikolayevich comes up with an idea of improved arc lamp—without regulating distance between electrodes—future "Yablochkov candle."*[47]

> *During one of his 1875 experiments on the electrolysis of coal, he accidentally produced a bright arc from two rods in parallel that illuminated his laboratory. The use of these parallel rods provided the foundation and inspiration for his improvements to the arc lamp, which eventually became the Yablochkov Candle.*[48]

When his workshop hardly survived a financial crisis, he decided to go to America. But on his way to Philadelphia he got stuck in Paris.

> [Pavel Nikolayevich Jablochkoff] *had retired from the army in order to devote himself to the invention of an electrical light and decided to visit the Philadelphia Centennial Exposition of 1876. However, he tarried in Paris in order to visit Breguet's electrical shop, where both Gramme dynamos and Serrin regulators were constructed; and he was so fascinated by what he saw that he never finished his journey. Instead, he found employment at Breguet's shop and stayed there for a number of years. After patenting a novel kind of electromagnet, he turned to the electrical lamp, and the innovations he introduced gave a tremendous impetus to the commercial application and exploitation of the dynamo. Jablochkoff found a means of producing a carbon arc that regulated itself without the use of any mechanism…The "Jablochkoff´ candle" made possible the first electric illumination on a broad commercial scale.*
> (King, 1962, pp. 393, 395)

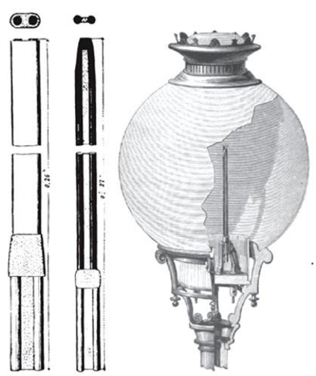


Figure 40: Jablochkoff's candle (1876) and globe unit holding the candle (right, 1878).

Source: www.ieeeghn.org/.

Jablochkoff's idea was quite simple. Instead of positioning the carbon rods opposite each other, he placed them

[47] Source: http://www.russia-ic.com/education_science/gems/ 661/#.VETFTCKsUr0. (Accessed November 2014)

[48] Source: http://www.ieeeghn.org/wiki/index.php/Pavel_Nikolayevich_Yablochkov. (accessed October 2014)

parallel at a distance that enabled the creation of a spark. Both rods would be burning at the same rate, like a traditional wax candle. And using in one armature several carbon pairs, which could be switched on mechanically, he created a more practical arc light.

> *With his design, Jablochkoff solved two of the problems of the subdivision of the electric light—that of placing several lights in the same circuit and that of reducing the intensity of the arc light.* (King, 1962, p. 395)

However, in addition to the fact that they only lasted for two hours, there were some other disadvantages:

> [The Jablochkoff candle] *which wasted a great deal of light upward; could not be relighted after being extinguished, was noisy, required alternating current, and gave a fluctuating light output.* (Bright, 1949, p. 29)

Jablochkoff did protect his discovery by patents. He was granted French-patent №. 112,024 on March 23, 1876, and British-patent №. 3,552 on September 11, 1876 for his design. On May 15, 1877 he was granted US-Patent №. 190,864 (reissued in November 1881 as RE9935) for his electric arc lamp. In the specification for the US patent №. 190,864 (Figure 41) he stated:

> *The object I have had in view in inventing my new system of electric lamp is the absolute suppression of any mechanical regulator, which is generally used in ordinary electric lamps. Instead of realizing in a mechanical manner the automatical drawing nearer of the conductor-coals, in proportion to their combustion, I have conceived the idea of fixing them in a parallel manner at a short distance from each other, and separating them by an isolating substance which is susceptible of consumption at the same time with the coals.* (Yablochkoff, 1877)

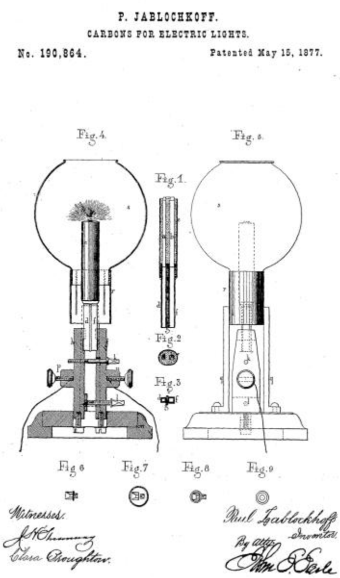


Figure 41: US Patent 190,864 for the Jablochkoff arc lamp (1877).
Source: USPTO.

French businessmen saw its potential and undertook action that resulted in setting up a company, Compagnie Générale d'Électriqué (CGE), to manufacture and market it.

> *A Russian gentleman, M. Wyrouboff, director of the Revue Positiviste, introduced him* [Jablochkoff] *to M. S. Denayrouze, and at the commencement of 1877 a group of capitalists combined in the form of a syndicate, for the investigation of electric lighting, with a capital of half a million francs. Afterwards this syndicate was transformed into the Societe Generale d'Electricite (precedes Jablochkoff), and more recently into the Compagnie Generale d'Electricite, with a capital of 20,000,000 francs.* (J. Dredge, 1882, p. 513)

Next to this entrepreneurial interest, the development of the new candle also attracted interest in the scientific circles in Paris.

> *The electric candle was presented to the Academy of Sciences by the President, M. J. B. Dumas, in the name of M. Denayrouze. On that occasion M. Dumas spoke as follows:—'I have the honour to bring before the notice of the Academy, the results of investigations by M. P. Jablochkoff on an invention which has made a great step in the problem of electric lighting. This discovery involves first the suppression of all the mechanism usually employed in ordinary electric lamps. The new luminous source is composed of two carbons fixed parallel to each other, a slight distance apart, and separated by an insulating material which is consumed at the same rate as the carbons themselves.* (Ibid.)

The lamp was an immediate success, especially after the demonstrations at the Paris World Fair of 1878, where visitors were flabbergasted by the new electric lamps that were demonstrated. Companies like Gramme's and Siemens & Halske were quick to develop special, single-phase dynamos for use with Jablochkoff's system, like Gramme's dynamo for a four-circuit Jablochkoff system with four candles per circuit. To solve the problem of the changing of the electrodes when they were burned out, special mechanisms were developed to easily switch carbon rods (Figure 42). A lot of those rods were consumed by the increasing number of applications. Electrodes thus were made in a factory at No. 61 Avenue de Villiers in considerable quantities] (Moncel, 1883, p. 219).

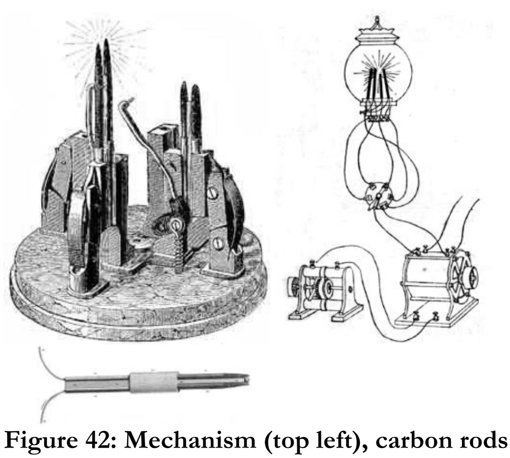


Figure 42: Mechanism (top left), carbon rods (below left), and Gramme "battery" (right) for Jablochkoff's candle.

Source: www.geopedia.fr. http://seaus.free.fr/spip.php?article500.

All those candles were used to fuel the Jablochkoff armatures that appeared in more or less open "public areas" all over Europe (Figure 43, Figure 44):

> *In April 1877, 16 of the "candles" were placed in the Grand Magasins du Louvre in Paris. The Parisian Hippodroine followed a short time later with a system that included both Serrin regulators and Jablochkoff candles."…In December 1878 the Municipal Council of Paris decided to try the "candles" for public illumination, in competition with gas, for one year. London imitated the example of Paris a short time later. After trying the Jablochkoff system on an experimental scale at Billingsgate Market, in December 1878 the municipal government installed 20 "candles" along the Thames Embankment and 16 along the Holborn Viaduct…For a while it seemed as if the Jablochkoff system might be the solution to the problem of the electric light. During the next few years its application expanded quite rapidly; in addition to its use in cities…it was utilized to light the cabins of ships.* (King, 1962, pp. 404, 406).

Next to street lighting, station lighting, exhibition lightning, and so on, the Jablochkoff candle also was used in more closed "public areas" like opera buildings and theatres, hotels, and big shops (the socalled "Grands Magasins"). It was often an additional attraction to show the "modernity" of the location, like at the highest hotel in Europe.

> *The electric light has made its way to the highest hotel of Europe, i.e., to the hotel which is situated at the greatest elevation above the sea level. The Engadiner Kulm Hotel at St. Moritz, in the Upper Engadine, boasts of an elevation of 1,856 metres above the sea, and the proprietor announces that the establishment now possesses eight Jablochkoff lamps. A waterwheel is the motor of the electric machine feeding the lamps.* [49]

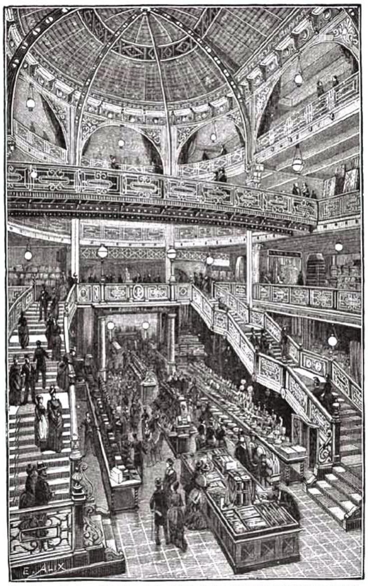


Fig. 365. — Eclairage électrique de la nef des *Grands Magasins du Printemps*, à Paris.

Figure 43: Jablochkoff's candles at the Grands Magasins du Printemps (Paris).

Source: Internet.

[49] Source: Notes. *Nature, August 21, 1879. P.401 http://www.mocavo.com/Nature-a-Weekly-Illustrated-Journal-of-Science-May-Oct-1879-Volume-20/316061/562#562 (Accessed November 2014)*

In 1879 Pavel Jablochkoff established the *Electric Lighting Company, P. N. Yablochkov the Inventor and Co*, and an electrical plant in Petersburg that would later produce illuminators for military vessels and industrial factories. His lamp became quite popular, not in the least because the total system was more cost-effective than the former lamps. Several of Jablochkoff's candles could be connected in series to one AC generator, compared to the Lontin-Serrin regulator arc lights that each required a separate Gramme generator. He also patented this system (Figure 41). It was the Jablochkoff "candle" that enabled the first electric illumination on a broad commercial scale and created a considerable societal impact.

Table 2: Some of the Jablochkoff's French, British, and US patents granted for early arc lights and additional equipment

Patent №.	Filed	Granted	Category
Fr 112,024	unknown	March 23, 1876	-
GB 3,552		September 11, 1876	-
US 190,864	December 30, 1876	May 15, 1977	Improvements in carbons for electric light
US 9,935	September 27, 1881	November 15, 1881	Electric lamp
US 248,654	June 4, 1881	October 25, 1881	Secondary electric battery
US 266,993	September 6,1882	November 7, 1882	Dynamoelectric machine to be used as generator or motor*
US 273,739	September 14, 1882	March 13, 1883	Electric battery

* Also patented in France patent on May 2, 1882, and England on June 13, 1882.

Source: USPTO

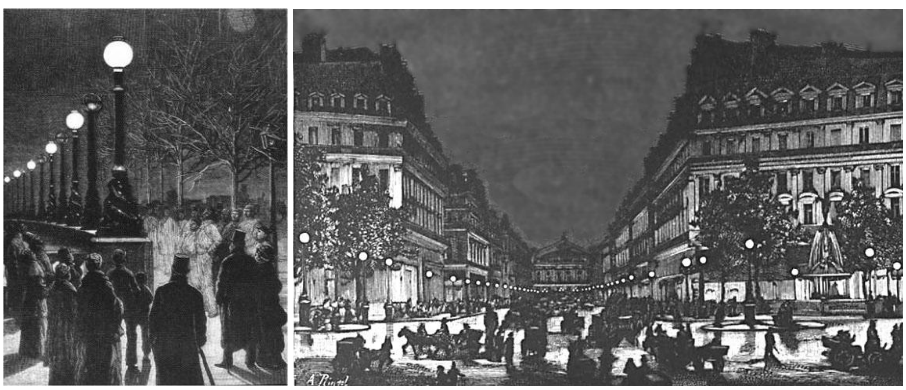


Figure 44: Jablochkoff Candles on the Victoria Embankment in London (December 1878) and, right, on the Avenue de l'Opera in Paris (1878).

Source: Wikimedia Commons. Alglave, E.: The Electric Light: Its History, Production and Application (1884).

Jablochkoff's concept improved

After Jablochkoff's candle there came many variations on his design, like the mechanical designs for multielectrode brackets, metalized electrodes for longer duration, and so on. The Englishman H. Wilde, for example, devised and improved and patented a candle with parallel electrodes without the insulating material; they were held separated by an electromagnet when a current was present, thus igniting the arc automatically (GB-Patent №. 618, 1873; GB-Patent №. 3,250, 1878) (Figure 45). Others, like the Frenchman M. Reynier, tried to increase the "working" life span of the carbon by covering it with a thin film of metal. These improvements were patented, and they resulted in an infringement case.

> *The priority of this invention* [metallization of carbon] *has been warmly contested; in France it was for a long time attributed to M. Reynier, who secured it by a French patent dated 11th October, 1876. Fortified by this patent, which he considered original, M. Reynier commenced an action against the Jablochkoff Company, who, relying on certain prior publications, electro-plated the carbons they employed without paying him any royalty. The case went to trial and was decided, on the 21st July 1881, in favour of the Compagnie Generale d'Electricite. In the course of the action certain facts, before almost unknown, were brought forward and threw a new light on the history of this invention. There were found in several English patents certain intimations, though not well defined, of the association of metals, especially of copper, with electric carbon…The Tribunal Correctionnel of the Seine decided that he was in error, and that the process of metal coating carbons for the electric light belonged to the world.* (J. Dredge, 1882, pp. 517-518)

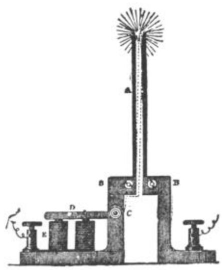


Figure 45: Wilde candle with parallel carbon electrodes.

Source: O'Connor, Standard Electrical Dictionary. http://www. gutenberg. org/files/26535/26535-h/26535-h.htm.

Later versions of arc lights

The success of the Jablochkoff candle with its double-electrode system did not mean that the older systems were not applied anymore. The older systems stayed in production and were improved, and new lamps developed. Most inventors normally designed a dynamo as well as a lamp, and the variety of equipment available grew rapidly. Some created more ornamental arc lights, like the *Jolin-Parsons, Lever* and *Pilsen* arc lamps. Other inventors of arc lights continued on the path of trying to regulate the distance between the rods mechanically or electromechanically. They covered their work in the electric lamps with patents, often in combination with patents for dynamos. It resulted in an explosion of patents. In England over the period 1877–1881, 189 patents were filed for improvements in arc lamps. In the United States of America in the period 1877–1881, seventy-three patents were granted (J. Dredge, 1882, pp. Subject matter index GB patents, list of USA patents). We will try to describe some of the major developments.

Charles Brush: An arc-light system (1878)

Charles Brush (1849–1929), a graduate of the University of Michigan, was familiar with Davy's experiments with the arc light supplied with electricity from a battery. In developing an arc lighting system, Brush initially concentrated on finding an economical source of electric power: the dynamo (Figure 46). Originally the young Brush consulted for the Cleveland Telegraph Supply Company, a manufacturer of telegraph instruments, electric bells, and fire alarm systems. As Brush mentioned to the manager George W. Stockly that he could build a more efficient dynamo, his offer was accepted.

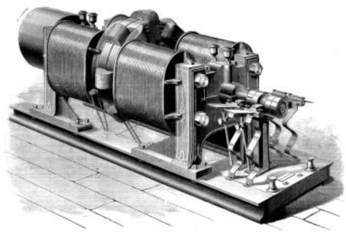


Figure 46: Brush dynamo-electric machine.

Source: Scientific American, 1881, http://www.machine-history.com/.

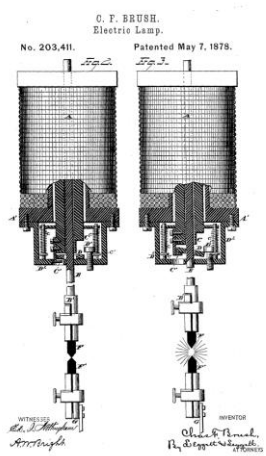


Figure 47: Arc light regulator: details from US patent 203,411, May 7, 1878, of Charles Brush.

Source: USPTO.

He went to his country home near Wickliffe and set to work. When toward the end of the summer of 1876 he drove to the door of Stockly's office in a buggy, there was on the seat beside him a machine that looked no larger than a model, hand-built throughout except for iron castings furnished by the Telegraph Supply Company. The machine was taken into the company's shop and connected to an arc lamp. The shaft of the armature was belted to the main shaft of the shop. It was a tense moment when the engine started. Brush with his dynamo stood at the limit of electrical knowledge. Was he to pass a boundary? The lamp, shining steadily, signaled his advance in dispelling some of the darkness that lay beyond. Brush had fulfilled his promise to Stockly, but he still needed an arc lamp to go with his dynamo. In that period there were not many lamps to be found and none of those tested

> *gave the results that Brush desired. Finally he under took to design one of his own…Two years later Brush completed his memorable invention of a series arc lamp with regulating shunt coil. This invention, which enabled him to introduce arc lighting from central stations as a commercial venture, marked the birth of that industry…In the winter of 1876–77, the company [the Telegraph Supply Company] entered into a formal agreement with Brush whereby they received the sole right to manufacture and sell the Brush system under any patents the latter might obtain.* (Hammond, 1941, pp. 8, 9)

Having this vision of lighting America on a grand scale, Brush continued the development of his electric arc system (arc lamp with regulator, dynamo, and accessories). The generator was a key component, as it replaced the cumbersome batteries.

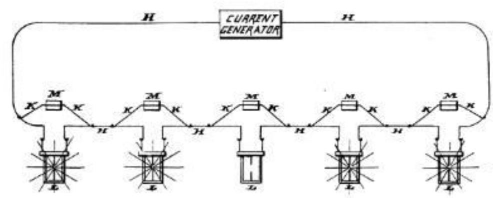


Figure 48: Details from US patent 234,456 of November 16, 1880, of Charles Brush.

Source: USPTO.

On May 7, 1878, he was granted US-Patent №. 203,411 for his regulator for an arc light (Figure 47), followed by US patents №. 219,208 of September 2, 1879, for an improvement; №. 212,183 on February 11, 1879 (improvement); and №. 312,184 on February 10, 1885 (improvement). In addition, US-Patent №. 234,456 was granted on November 16, 1880, for a multi-lamp system: the "Automatic Cut-Out Apparatus for Electric Lights or Motors." It placed the lamps in series with one another (Figure 48).

Brush understood that he had to create interest in his new product, so he paid considerable attention to the marketing of his product by demonstrating it wherever he could, like in John Wanamaker´s Grand Depot (Figure 49).

> *In 1877, however, two of Brush's small-size dynamos and two of his lamps came suddenly into prominence among several contemporary machines that were tested by the Franklin Institute of Philadelphia. The committee which studied these machines was composed of two men, Professors Edwin J. Houston and Elihu Thomson…The first Brush arc lamps were installed in Philadelphia at the store of John Wanamaker. Five Brush dynamos were put to work, each supplying current to four arc lamps in the windows of the store. These lights became one of the wonders of 1878. People gathered in throngs on the sidewalk to examine them. For weeks they were talked about and a contemporary writer called them "miniature moons on carbon points, held captive in glass globes."…This first Cleveland installation was a modest one. Twelve lamps, mounted on eighteen-foot*

Figure 49: John Wanamaker´s Grand Depot (ca. 1880).

Source: Free Library of Philadelphia, www. http://explorepahistory.com/.

posts, were supplied with current from a Brush dynamo in the Telegraph Supply Company's shop. They were first lighted on April 29, 1879. The Cleveland Plain Dealer, describing the scene the day after the lights were first turned on, said: "Thousands of people gathered…and as the light shot around and through the Park a shout was raised. Presently the Grays Band struck up in the pavilion, and soon afterward a section of artillery on the lake shore began firing a salute in honor of the occasion."…

Niagara Falls was illuminated for the first time on July 4, 1879, by a sixteen-light Brush dynamo and arc lamps. The dynamo, driven by a waterwheel, was a pioneer hydroelectric plant. A full complement of lamps was always operated; there was no need to switch off some and leave the rest burning. (Hammond, 1941, pp. 10, 13, 28, 30)

Brush's system of arc light became well-known. It would be the base for his entrepreneurial activities.

Elihu Thomson and Edwin J. Houston (1879)

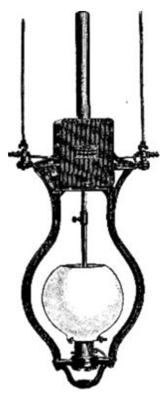


Figure 50: Thomson arc lamp.

Source: Scientific American Supplement, Vol. XV., No. 388, June 9, 1883. http://www.gutenberg.org/files/15417/15417-h/15417-h.htm#art15.

Elihu Thomson (1853–1937), born in England, went with his family to the United States of America in 1858 and became a professor in chemistry. Edwin Houston (1847–1914), born in Alexandria, Virginia, was a professor of civil engineering for a short period before holding the chair of Natural Philosophy and Physical Geography. Both were teaching at the Boys' Central High School of Philadelphia when they became interested in arc lighting in 1878, when some Brush lamps were installed in a Philadelphia store window. The next step was to manufacture the lamps. They needed financial backing, and they needed to secure their designs.

Thomson and Houston designed an improved dynamo and arc lamp of their own (US patent №. 220.287 granted on October 7th, 1879) and made a few small installations with the aid of a local backer. In 1880 Thomson accepted the offer of a group of individuals in New Britain, Connecticut, to finance the manufacture of arc lamps, dynamos, and other apparatus under Thomson and Houston patents. Thomson remained at his teaching. Elihu Thomson patented his arc light in July 25th, 1882 with US-patent №. 261.790, followed with US-patent №. 335.159 in February 2nd, 1886 for a "system of distribution." Edwin Houston was granted US Patent №. 259.017 on June 6, 1882 for an incandescent lamp. (Bright, 1949, p. 31)

The result was that they created an arc lamp (Figure 50), improved upon it, and patented it heavily (Table 3).

Table 3: Some patents granted to Elihu Thomson and Edwin Houston for arc lamp (regulators)

Patent №.	Granted	Description
US 220,287	October 7, 1879	Improvement in regulators for electric lamps: Regulator for electric lamps, electromagnet-controlled position of electrodes (E. Houston/E. Thomson)
US 223,646	January 20, 1880	Improvement in regulators for electric lamps: Regulator for electric lamps, motor-controlled position of electrodes (E. Houston/E. Thomson)
US 250,463	December 6, 1881	Improvement in regulators for electric lamps: Regulator for electric lamps, motor-controlled position of electrodes
US 258,684	May 30, 1882	Electric-arc lamp: Lamps adapted to dynamos that are excited by separate currents
US 261,790	July 25, 1882	Electric-arc lamp: Improvement on the drop and lift mechanism
US 272,353	February 13, 1883	Electromagnetic retarding device: Device used in electric arc light
US 283,167	August 14, 1883	Electric commutator or switch: Interrupting electric currents in arc light systems

Source: USPTO.

Rookes E. B.Crompton (1882)

The Englishman Rookes Crompton (1845–1940), born in Sion Hill, Yorkshire, became fascinated with steam engines after visiting the London Great Exhibition of 1851 as a kid. After a period of training in the engineering shops of the Great Northern Railway at Doncaster, Crompton was enlisted as an ensign in the 3rd Battalion of the Rifle Brigade in April 1864. Later that year he sailed for India where he, as superintendent of the Government Steam Train Department, got involved in (steam) traction engines and steam lorries. He spent twenty years in India before returning to England and became partner at T. H. P. Dennis & Co.

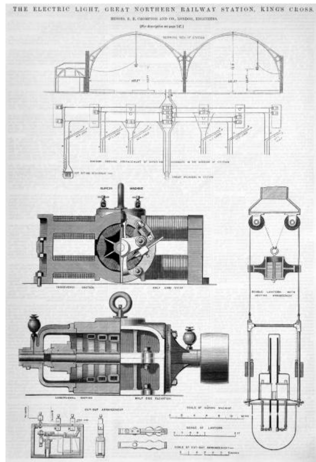


Figure 51: Crompton's light system for the Great Northern Railway Station at Kings Cross (ca. 1883).

Source: http://www.gracesguide.co.uk.

One of his first accomplishments was the installation of a Gramme dynamo and arc lamps on a license from Bürgin in Switzerland to improve night work conditions at his brother's foundry. As he was dissatisfied with the French lamps he was importing, he designed a lamp of his own, based on the successful Serrin lamp. He obtained many patents (more than one hundred in the period 1878–1899), among which were GB-Patent №. 3,339 of June 14, 1882, for an arc-lamp regulator and GB-Patent №. 4,810 of October 10, 1882, for a compound-wound dynamo. He used his arc-lamp design to develop the military searchlight. In 1878 he took over T. H. P. Dennis and Co.'s company and created Crompton and Co. This company became England's leading distributor and manufacturer of electricity generating and lighting systems. In 1881 his company developed enclosures for the lamps, which allowed electric lighting of coal mines, and carried out an installation at a colliery near Mansfield. In 1881 the company lit King's Cross Railway Station (Figure 51) (Bowers, 1969; Russell, 1941).

Edward Weston (1883)

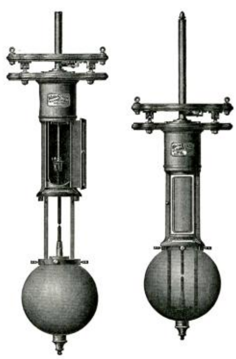


Figure 52: Weston arc light based on US patent 285,451 (ca. 1883).

Source: weston.ftldesign.com.

Edward Weston (1850–1936), born in England, emigrated to the United States in 1870 and started working in the electroplating industry, where he, after the bankruptcy of his employer, the American Nickel Plating Company, started in 1872 with an electroplating company in partnership with George G. Harris. His first dynamo was developed in 1873. In 1876 Weston was contacted by Frederick Stevens, who offered Weston the opportunity to set up a dynamo division of his Steven, Roberts & Havell Company. His US-patent №. RE8141, filed on July 10, 1877, and granted on March 26, 1878, was partly assigned to Roberts & Havell. In 1877 the division was organized as a separate company, the *Weston*

Dynamo Machine Company, in Newark, New Jersey.

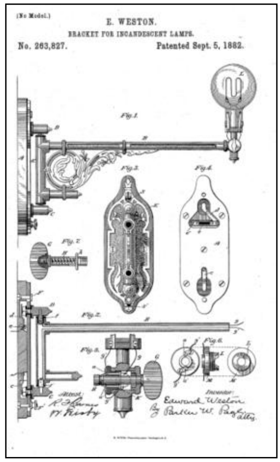


Figure 53: Weston incandescent lamp holder from US patent 263,827 (ca. 1882)

Source: USPTO.

In 1880 the firm's name was changed to the Weston Electric Light Company. Ten years after his arrival in the United States, at the age of thirty, on July 16, 1880, he filed for protection of his invention, which was granted as US-patent №. 285,451 on September 25, 1883, for an arc light (Figure 52). Initially his attention was directed more to arc lighting, and it was not until after 1880 that he made his most important contribution to the incandescent lamp—the Tamidine filament, a carbon material that gave a bulb life of up to 2,000 hours. By 1886 had been granted 186 patents (Table 4). At that time he was thirty-six years old. In total Edward Weston attained 334 US patents. It required a considerable effort to uphold his patent rights.

> *Like many inventors, Weston has been engaged extensively in patent litigation. To uphold some of his*

Table 4: Some patents granted to Edward Weston

Patent №	Granted	Description
US 196,846	November 6, 1877	Improvement in compound switches in dynamoelectric machines employed in the art of electroplating (filed August 24, 1877)
US 201,140	March 12, 1878	Improvement in oilers (filed February 13, 1878)
US 211,070	December 17, 1878	Improvement in manufacture of metallic nickel (filed December 4, 1878)
RE8141	March 26, 1878	Improvement in dynamoelectric machines (filed July 10, 1877)
US 209,532	October 29, 1878	Improvement in dynamoelectric machines (filed December 31, 1877)
US 210,380	November 26, 1878	Improvement in electric lights (filed 4, 1878)
US 263,827	September 5, 1882	Bracket for incandescent lamp (filed February 18, 1882)
US 283,544	August 21, 1883	Vacuum apparatus: for exhausting incandescent lamps (filed December 14, 1880)
US 264,983	September 26, 1882	System for electrical transmission of power (filed May 8, 1862)
US 266,741	October. 31, 1882	Incandescent electric lamp (filed July 19, 1882)
US 285,451	September 25, 1883	Electric lamp: Arc lamp (filed July 16, 1880)
US 289,327	November 27, 1883	Apparatus for treating carbon conductors (filed July 31, 1883)
US 316,088	April 21, 1885	Incandescent lamp holder

Source: USPTO.

rights, he had to spend on one set of patents nearly $400,000, a large amount of money for anybody, but, as he told me, he begrudges less the money it cost him than all his valuable time it, required—a greater loss to an inventor thus distracted from his work. (Baekeland, 1915, p. 248)

The development of the arc light continued for quite a long time, till the end of the nineteenth century. It was, for example, Nikola Tesla who patented his invention for an arc lamp powered by AC electricity: US-patent №. 335,786, granted on February 8, 1886. But it still was a "linear arc lamp," in which the distance between the opposite electrodes were controlled by electromagnets.

Applications of arc lights

Originally the arc lamps were used in lighthouses and (military) searchlights (Figure 54). For many of the inventors of a dynamo, the applications of arc lights created opportunities to do business.

In 1873 Wilde directed the attention of the Admiralty to the advantages of electric searchlights for naval purposes. Experiments were made at Spithead, extending over a year. They were especially arranged so as to ascertain whether the searchlight would be a useful protection against torpedo boats. The experiments were so successful that three warships, the Minotaur, the Alexandra and the Temeraire were fitted with Wilde's apparatus. The report of Admiral Sir Beauchamp Seymour stated that the searchlights were of very great value for navigation, signaling, and general naval manoeuvres. Wilde also introduced his inventions to the Mercantile Marine service, but the Admiralty claimed the exclusive use of the lights. After the loss of the Titanic, Dr. Wilde communicated

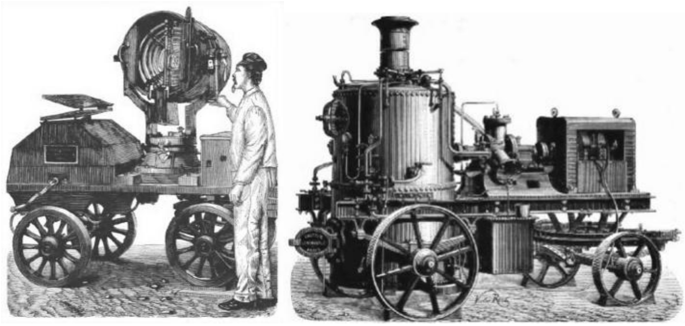


Figure 54: French military searchlight projector (left) and a mobile military steam engine powering a Brotherhood motor and Gramme electric generator (right), designed by Colonel Mangin, circa 1880.

Source: http://ancientskyscraper.com/85601.html.

> *two papers to the Society: "On Searchlights for the Mercantile Marine," and "On Searchlights and the Titanic disaster," in which he strongly urged the compulsory international use of searchlights at sea.* (Haldane Gee, 1920, p. 7)

Next to military applications, another application for the arc light developed. It was the lighting of public places in the form of street lighting. The powerful arc lights were used to create "artificial moonlight," that is, they were located in a central point in town, on a high building or a tower like construction, as in the city of Wabash. The sleepy hamlet of Wabash was the first Indiana town to grasp the glamour and social prestige of spectacular lighting. The city fathers hired the Brush company to set up four three-thousand-candle arc lights on the courthouse (Nye, 1990, p. 3).

Figure 56: Maintenance of arc lamps (ca. 1890).

http://www.hevac-heritage.org/.

Soon candles could also be found used as streetlights, for example, the Jablochkoff candles lighting the Avenue de l'Opera and the Place de l'Opera in 1878—quite a happening, which was one of the reasons why Paris earned its "City of Lights" nickname. In London the first electric street lighting with arc lamps was on the Holborn Viaduct (a road bridge) and the Victoria Embankment and Thames Embankment (1878). The first major installation in Germany was for streetlamps on the Potsdamer Platz in Berlin. The maintenance (usually daily adjustment) of all these street-lighting systems installed in the United States and Europe usually required an army of technicians (Figure 56). Their work on those magic devices was also an object of curiosity for many (Figure 55).

Figure 55: Replacement of electrodes (Berlin, 1889).

Source: Wikimedia Commons.

Another public application of arc lamps (the "electric candle," as they were called) was for the lighting of large shops (Grand Magasins), high-end restaurants, theatres, exhibitions, and horse stables. Jablochkoff's candles were first used to light the Grand Magasins du Louvre in Paris, where eighty lamps were deployed. They were also used at the Paris Exhibition of 1878:

> *From June 7 up to the end of the month the exhibition of Beaux Arts at the Paris Palais de I'Industrie will be lighted every night by electricity. The motive power Is supplied by 262 Jablochkoff electric lights. 120 have been distributed in the gardens where statues are exhibited; 142 in the saloons where pictures are suspended on walls. The 120 candles are surrounded by opaline globes, which diminish the total effect, but the general illumination is satisfactory. The other 142 have been placed in translucent glass spheres, which leaves the light its original force. The appearance of the pictures is splendid and the general impression is exceedingly favourable.* [50]

Complaints often were made that the arc light was too glaring, although it was pointed out to such critics that so, also, was the sun. Nevertheless, the intensity of the arc light proved to be a stumbling block to other uses of electricity than for "public" lighting (King, 1962, p. 340).

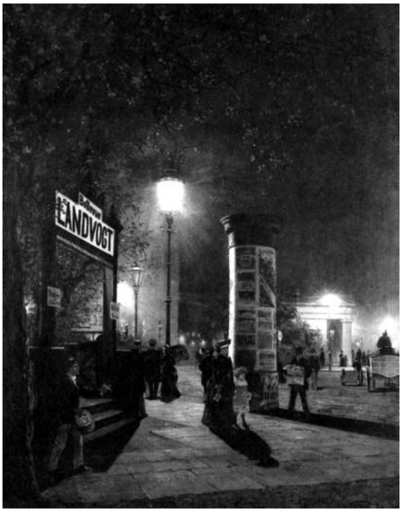


Figure 57: Arc lamps in Berlin (1884).

Source: Museumsstiftung Post und Telekommunikation Wikimedia Commons.

For home use the light was too bright, blinding when looked at. The power supply was problematic, as the generator could quite well handle the arc lamps on a one-to-one basis; using more lamps on one generator (placed in series) was problematic and reduced their light output. The carbons in the lamps themselves were sensitive and needed constant adjustments and frequent replacement.

This meant that arc systems were limited in their application. By the end of the nineteenth century, the end was near for the arc lamp, as other lamps were making it obsolete. Enclosed-flame arc lamps were the final major development in arc-lamp design. In an enclosed lamp, the arc was contained in a small glass tube within the main globe of the lamp. This restricted the flow of air around the arc and reduced the consumption of the carbons by a factor of about five. Enclosed arc lamps, therefore, had reduced maintenance costs, but required more power.

[50] Source: Notes. *Nature, June 12, 1879. P.161 http://www.mocavo.com/Nature-a-Weekly-Illustrated-Journal-of-Science-May-Oct-1879-Volume-20/316061/562#562 (Accessed November 2014)*

What was needed was another invention, a lamp that could be used in smaller, indoor spaces, that could be turned on and off individually, that did not smell, and that gave a "pleasant" light. But before that was ready to happen, it was the arc light that had created a revolution in the industry.

> *The incentives for the development of a new and more generally satisfactory light source were great for both inventors and capitalists. The possible financial reward for a successful lamp was enormous. Moreover, the prospective glory of being the victorious inventor was in itself an ample reward for some.* (Bright, 1949, p. 34)

The invention of the arc lamp

As shown in the preceding, the invention of the arc light is not the result of the inventive experimenting of one person. From the first moment Humphry Davy demonstrated at the Royal Institute in London in the early 1800s the sparkling light due to short-circuiting the voltaic battery till Jablochkoff's candle in the 1870s took a period of several decenniums. In between, countless people experimented with regulators: mechanical and electrical-powered machines that kept the arc burning. They created complex mechanisms, but the battery-powered arc light was, also due to the missing source of the dynamo, only used for the more eccentric applications like theatres, streetlight towers, and lighthouses. When the first dynamos were invented and could power the arc light, the development speeded up. Street lighting and illuminating other public places were realized by arc lamps.

From a *technological point of view*, the development was focused on the "regulator mechanisms." Some mechanisms became more popular (Serrin, Dubosq), while others became obscure. The technical construction was less complicated with Pavel Jablochkoff's "candle." His idea to apply *parallel* electrodes was quite inventive. It eliminated the complex regulating mechanisms of the earlier developed lamps, where the electrodes were *in line* opposite one another. It was an idea soon to be copied by others. His invention even resulted in some litigation about the metallization of the carbons. Jablochkoff's invention was considered to be a breakthrough:

> *It was quickly found that the electric difficulty of subdividing the light, added to the great cost of the lamps then made, was an apparently insurmountable obstacle to its general adoption, and the electric light was gradually taking its place as a brilliant scientific toy, when the world was startled by the introduction of the Jablochkoff candle, which may fairly claim to have given a greater impetus to the new light than any previous invention, a stimulus without which it is even probable that electric lighting might have slumbered for another decade.*
> (Daft, 1881-1882)

In terms of *impact on society*, the Jablochkoff candle became commercially popular and was used on a larger scale than ever before. But the basic principle of the arc light itself (the smelly gasses, overly bright spark, high maintenance) hindered a massive penetration. True, hundreds of his lamps went into service between 1876 and 1878, mostly in big cities like Paris, Berlin, and London, lighting public places like the Gare du Nord and the Grands Magasins du Louvre. London followed suit later in 1878, when six lamps were installed in the Gaiety Theatre in the Strand, powered by their own steam-driven generator. When even more powerful generators became available, the arc light could be switched on individually, and the light burned longer in protective bulbs, it still was limited in its general use.

> *Until 1870, indeed, the electric light was familiar only to a few specialists, and existed as a scientific wonder, scarcely leaving the laboratory except for exhibition purposes, or in some rare cases where the rapid execution of public works rendered economy a very minor consideration, and where the regularity of the light was but of little importance. To-day [1882] the electric lights of many systems burns in*

Table 5: Overview of patents for the arc lamp (1841–1876)

Patent №	Year	Patentee	Description
GB 10,548	March 10, 1845	T. Wright	Electric light/Arc lamp: mechanical regulation of rotating disc
GB 11,449	November 12, 1846	W. E. Straite	Lighting by means of electricity/Arc lamps: glass globe encapsulation of carbons, clockwork regulation
GB 11,783	July 3, 1847	W. E. Straite	Lighting by electricity—Arc lamps
GB 2,458	October 20, 1856	J. Lacassagne	Electric lamps/Differential arc lamp
GB 2,547	October 29, 1856	J. T. Way	Electric lights/Electric lamp
GB 1,033	April 13, 1857	J. B. Pascal	Electric lamps
GB 1,258	May 4, 1857	J. T. Way	Obtaining light by electricity/Electric lamps
GB 2,628	October 14, 1857	F. H. Holmes	Magnetoelectric machines/Electric lamp
GB 2,368	October 23, 1858	E. C. Shephard	Electric lamps/Incandescent arc lamp
GB 653	March 15, 1859	W. Clark	Apparatus for regulating electric lamps or lights/Arc lamp
FR 112,024	March 23, 1876	P. Jablochkoff	Arc light
US 190,864	May 15, 1877	P. Jablochkoff	Improvement in carbons for electric lights: absolute suppression of any mechanical regulator, which is generally used in ordinary electric lamps

Source: USPTO; French and British patents (J. Dredge, 1882).

thousands of lamps. Whole districts of London, Paris and New York are lighted by it, and hundreds of workshops employ it, to the exclusion of gas.

In many railway stations, cafes, public offices and stores, and in some theatres, it supplies the sole means of illumination, and it may be confidently expected that before long it will be brought widely into private dwellings. And to whom in future years will the honour of this revolution be accorded ? To no one person certainly, but amongst the crowd of scientific workers, it is evident that a first place must be accorded to M. Gramme, and to M. Jablochkoff. (J. Dredge, 1882, p. 512)

Table 6: Overview of patents for the arc lamp (1876–1891)

Patent №	Year	Patentee	Description
FR 112 024	March 23, 1876	P. Jablochkoff	Arc light
US 190 864	May 15, 1877	P. Jablochkoff	Improvement in carbons for electric lights: Absolute suppression of any mechanical regulator, which is generally used in ordinary electric lamps
US 203 411	May 7, 1878	C. Brush	Improvement in electric lamps: Mechanism for automatic adjustment of carbon sticks
US 212 183	February 11, 1879	C. Brush	Improvement in electric-light regulators: Mechanism for automatic adjustment of carbon sticks
US 220 287	October 7, 1879	E. Thomson, E. Houston	Improvement in regulators for electric lamps/Regulator for electric lamps: Electromagnet-controlled position of electrodes
US 223 646	January 20, 1880	E. Houston, E. Thomson	Improvement in regulators for electric lamps/Regulator for electric lamps: motor-controlled position of electrodes
US 250 463	December 6, 1881	E. Thomson	Electric lamp/Regulator for electric lamps: Separation of carbon under control by shunt or derived circuit
US 243 341	June 21, 1881	F. von Hefner-Alteneck	Electric lamp: Differential mechanism for adjusting carbon rods
US 261 790	July 25, 1882	E. Thomson	Improvement in electric arc lamp: Mechanism for automatic adjustment of carbon sticks by an electromagnet
US 285 451	September 25, 1883	E. Weston	Improvement in electric lamp: Mechanism for automatic adjustment of carbon sticks by two electromagnets of different resistances
US 312 184	February 10, 1885	C. Brush	Improvement in electro-arc lamp: Mechanism for automatic adjustment of carbon sticks by two axial magnets
US 335 786	February 9, 1886	N. Tesla	Electric arc lamp: Position of electrodes controlled by electromagnets

Source: USPTO; French and British patents (J. Dredge, 1882)

That being said, certainly Jablochkoff's candle, due to its technical concept and its impact in society, deserves a mark as being an important invention.

Patent activity

All the described activities, experiments and developments for the arc lamp resulted in a range of inventions. The inventors often were keen to protect their "intellectual property" rights either to be known as the inventor or for monetary gain. Thus, the developments around the electric arc light resulted in a range of patents, indicating the innovative activity. In Table 5 an (indicative) overview is given of those patents that can be considered as being more or less important for the development of the arc lamp up to Jablochkoff's candle. Next to the early patents of a specific inventor, later patents for the same inventor and foreign patents are also indicated.

Jablochkoff's patents were just among the many that were applied for. They were not for the basic mechanism, but often for improvements around that concept, like the mechanism for the adjustment and position of the carbon sticks or the manufacturing of the carbon sticks. In Table 6 an overview is shown of some of the patents that were granted after Jablochkoff's patent.

A cluster of innovations for the arc-light

As can be concluded from the preceding, the discoveries by experimenting scientists like Petrov and Davy got a lot of attention and showed promise. It was in the early 1800s that the "sparks" bridging the "voltaic gap" were an item of curiosity to many (Figure 58). However, it took a while before that curiosity changed into useful devices. It was not before the late 1840s that mechanisms were developed that created an armature for maintaining and controlling the electric arc. The development of better batteries might have increased the interest in the arc light, but not enough to create widespread application. That changed with the development of the early electric dynamo. That was certainly a breakthrough. Now electicity was more easy to create, and it was available in greater volumes than ever in the case of the battery.

It stimulated the experimenters to improve upon the way the "voltaic gap" was maintained during the burning of the lamp. A range of inventive (mechanical) constructions was developed (Foucault, Statie, Serrin, etc.), which resulted in the application of the arc in places like the lighthouses. It was often in the combination of one arc light and one electric generator. That was a drawback that changed when more arc lights could be coupled to a single generator. Now the arc light could be used in public areas such as theatres, hotels, shops, and ships. The public interest was enormous; this was an invention that awed masses of people visiting the many exhibitions. But its use stayed limited as it still was a costly affair with high maintenance. In the meantime, generator development improved the reliability and available of electicity, and even more so when the self-exciting dynamo was developed.

Then came Jablochkoff's novel idea to configure the carbon rods in a way that increased their reliabiliy, lowered their cost, and reduced the maintenace. This was the breakthrough the arc light had been waiting for. Jablochkoff obtained patents in France, Britain, and the United States to protect his rights, and his arc lamps soon illuminated streets in Paris, London, and Berlin. The dynamo manufacurers were quick to develop dynamos that would feed the Jablochkoff arc light, or they started to manufacture complete systems themselves (Figure 59). It created a whole new business segment of the manufacturing industy of the electric light.

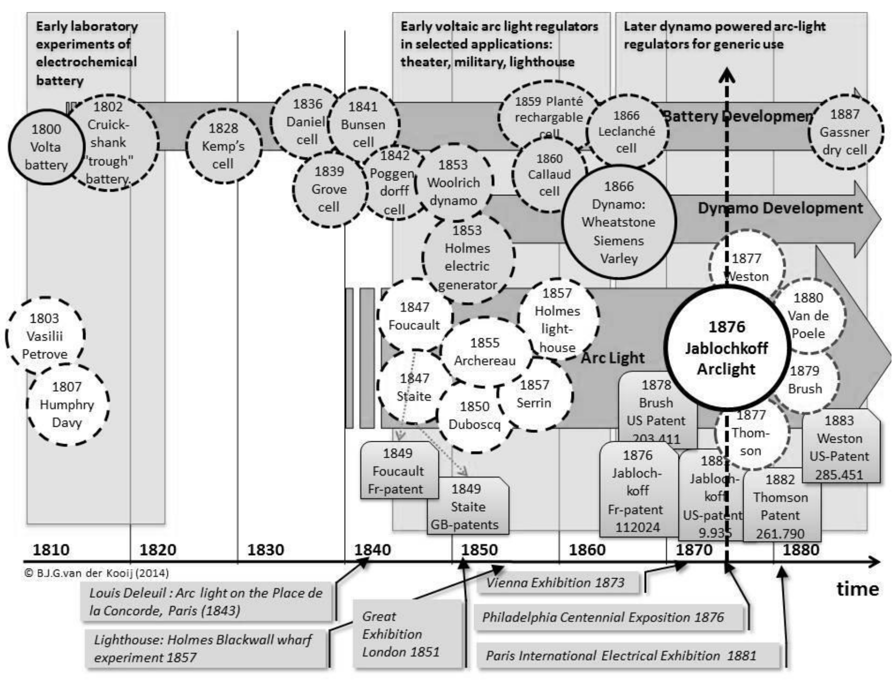


Figure 58: The cluster of innovations around the invention of the arc light.

The development of the supporting battery and dynamo technologies are separately indicated.

Source: Figure created by author.

Industrial bonanza: The arc-light manufacturers

Again it was a range of scientists and engineers who contributed in the development of the arc light, like the aforementioned Charles Brush (1849–1929), Edward Weston (1850–1936), Elihu Thomson (1853–1937), Sebastian Ferranti (1864–1930), and numerous others. These men created an industry that was highly competitive and used patents to strengthen their positions. To name only a few of the resulting companies, there were the Brush Electric Company (1880), the Weston Dynamo Machine Company (1879, later the Weston Electric Light Company, in 1881 the US Electric Light Company), and the American Electric Company (1880, later Thomson-Houston Electric Company)—and in England the Ferranti company.

> *Most of the American arc-lamp experimenters were young men, in their twenties or early thirties. This was true for all the electrical industries in the United States from 1875 to 1890, for it was a new and rapidly expanding field and drew its engineering personnel primarily from among the technically minded young men who had no previous ties—or only weak ones—with other occupations or industries. Although some of the inventors working before 1880 were university-trained, the majority were not. All, however, were enthusiastic about the possibilities of the practical application of electricity.* (Bright, 1949, p. 31)

They created companies that did not make just the dynamo and/or the arc light; they created "electrical systems" (Figure 59):

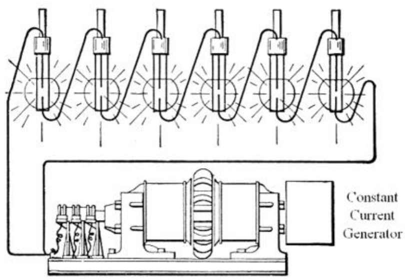


Figure 59: Electrical system of arc lamps.

Source:
http://www.ieeeghn.org/wiki/index.php/File:01series_arc_lights.gif.

> *The development was accomplished by "systems"; that is, each inventor, dozens of them, invented his particular dynamo, arc lamps, regulators and accessories, known as a "system," each exploited by its particular manufacturing company, and all competing intensively with each other. Each local company was organized to secure, or organized on the basis of having secured, one contract; that is, the municipal street lighting contract of its own city.* (Martin & Coles, 1919, p. 74)

All these companies were created and growing in a dynamic economic period. The Old and New World saw an economic depression (also called the Long Depression. 1873-1896). It started with the Panic of 1873 (both in

Europe and the USA due to post-war inflation, rampant speculative investments overwhelmingly in railroads, and large trade deficits) and ended after the Panic of 1893 (due to the collapse over railroad overbuilding and shaky railroad financing). This was the economic context within which the new "electric companies" operated.

In Britain the long depression resulted in bankruptcies, escalating unemployment, a halt in public works, and a major trade slump that lasted until 1897. The "Brush Bubble" of 1882 disrupted the stock trade and had the industry in turmoil. The early electric companies were also faced with more and more influence from the government, like the British Electric Light Act of 1882, which was concerned with the "supply of Electricity for Lighting and other purposes." It regulated and facilitated, among other things, the licenses to distribute electricity, the "breaking up of private streets, railways and tramways," the "obligations for undertakers to supply electricity," and the "stealing of electricity."

Charles Bruce and his "electric" business activities

One of the dominant players in the early development of "electric" companies in America was Brush Electric Company, capitalized at $3 million[51] and started by Charles Brush in 1880 in Cleveland. The aforementioned demonstrations attracted quite some publicity, but it was in 1880 that Brush really got a lot of attention—and free publicity—for his system at the small city of Wabash, Indiana, where he installed a system of "street lighting." The same was later done in New York:

> *The governing authorities of Wabash, Indiana, had found that electric lighting would not only cost some $800*[52] *a year less than gas lighting, but would yield a greater volume of illumination. Accordingly they contracted for a Brush installation with four lamps of 3000 candlepower each, mounted on cross arms atop the dome of the Court House 200 feet above the ground. This was the first municipally owned electric lighting plant, and Wabash the first town wholly lighted by electricity, for it was planned to illuminate the city from a single point. Both press and public followed the progress of the experiment with intense interest. Early on the day when the circuit was to be turned on, awed and wondering folk commenced to pour into Wabash from the surrounding country.*

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[51] This project would be equivalent to more than $60 million in 2010, based on a historic opportunity cost calculation. Source: Measuring Worth at www.measuringworth.com/uscompare/relativevalue.php.

[52] This commodity amount would be equivalent to more than $17,600 in 2010, calculated on the basis of real prices. Source: Measuring Worth at www.measuringworth.com/uscompare/relativevalue.php.

> *Newspaper correspondents traveled from cities as far distant as Chicago and New York. By 8:00 o'clock on the moonless evening of March 31, 1880, more than 10.000 persons were crowded about the Court House… Thus was Wabash given its baptism of light. For the moment Brush's competitors were out-distanced and forgotten… In December, 1880, Brush lamps were installed along Broadway for three-quarters of a mile, the first electrical illumination of the famous street. The operating organization was the Brush Electric Light and Power Company of New York. This company also contracted to illuminate Union and Madison Squares by means of masts 160 feet high.* (Hammond, 1941, pp. 31, 32, 41)

Having all this publicity and a market that admired the new phenomenon, Brush became even more active. In 1879 he sent Thomas J. Montgomery to England in an effort to market (the license of) his arc lamp there. Eventually this effort led to the formation of the *Anglo-American Brush Electric Light Corporation*. About the dominance of Brush companies, the *Scientific American* reported in an 1881 article:

> *Not only has the Brush light practically monopolized the field in this country, but, if we may judge from reports, it is also rapidly doing the same abroad. It has made wonderful advances in England, where it is controlled by the Anglo-American Brush Electric Light Corporation, Limited, having a capital of $4,000,000. One year ago this company bought the English patents of Mr. Brush at a very large price, and we understand they have recently purchased all his other foreign patents—those for France, Belgium, Austria, Russia, Italy, Spain, Norway, Sweden, Denmark, etc., paying for them still larger prices than they paid for the English patents, and they now propose to commence the introduction of the Brush light into all these countries in the same business-like and thorough manner which has characterized its management from the first. The sums paid for these foreign patents are, it is claimed, greater than have ever been paid for any other foreign patents obtained by an American. As rapidly as arrangements can be made the Brush light is being introduced into every civilized country on the globe, and it seems to have found a field in every branch of industry, and in almost every imaginable situation, as the following partial list of users indicates: There are 800 lights in rolling mills, steel works, shops, etc.; 1,240 lights in woolen, cotton, linen, silk, and other factories; 425 lights in large stores, hotels, churches, etc.; 250 lights in parks, docks, and summer resorts; 275 lights in railroad depots and shops; 130 lights in mines, smelting works, etc.; 380 lights in factories and establishments of various kinds; 1,500 lights in lighting stations, for city lighting, etc.; 1,200 lights in England and other foreign countries. A total of over 6,000 lights which are actually sold, none of them being on trial.* ("The Brush Electric Light," 1881)

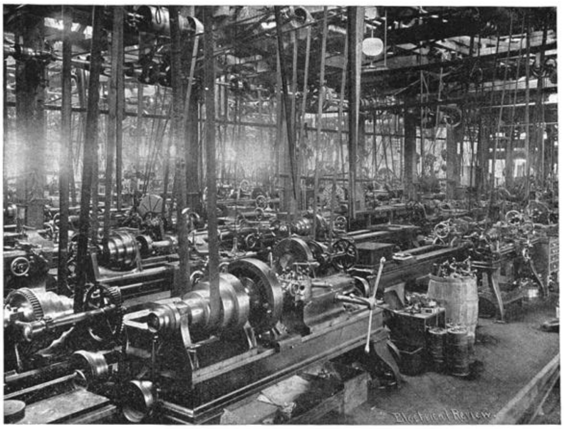

Figure 60: Main machine shop, Brush Electric Company, Cleveland.

Source: http://electricmuseum.com/.

The speculation around the Anglo-American Brush Electric Light Corporation would lead to a bubble on the English stock market: the "Brush Bubble".

Back in America Brush had created the—patent-holding—Brush Electric Company in 1880 and a subsidiary, the Brush Electric Illuminating Company of New York. An article "The Bruce Electric Light" in the *Scientific American* of April 2, 1881 describes his activities in New York:

> *The first lighting station of the company is at nos. 133 and 135 West, 5th street. It contains at present five dynamoelectric machines, the largest of which is 89 inches long, 28 inches wide, and 36 inches in height, and weighs 4,800 pounds, and runs at a speed of about 700 revolutions per minute. It is believed to be the largest machine in the world. Forty lights are fed by it, and it requires 36 horse power. Several circuits are connected with this station, one exclusively for lighting parks and streets. Broadway, from 14th to 34th street, is lighted from there. Among buildings in this district are the Sixth Avenue Elevated Railroad, the Sturtevant House, the Gilsey House, the Standard theatre, Daly's theatre, the Bijou theatre, the Aquarium, Aberle's theatre, Koster & Bial's, the Herald office, and many others. The company runs wires from this station to any point within a radius of two miles, putting up the light in any desired place, and renting in the same manner as is done with gas.* (American, 1881)[53]

Soon other subsidiaries would follow: New York, Philadelphia, Boston, Baltimore, Washington, Providence, Albany, Hartford, New Haven, Meriden, Rochester, Buffalo, Cleveland, Cincinnati, Dayton, Indianapolis, Columbus, Middletown, Detroit, Grand Rapids, Chicago, St. Louis, Denver, Salt Lake City, Ogden, Butte, San Francisco, and so on. (Figure 61)

[53] Source: Brush Electric Light, Scientific American, April 2, 1881. http://www.machine-history.com/Brush%20Electric%20Company. (Accessed November 2014)

> *With successful Brush streetlight systems in New York and Cleveland, a handful of Philadelphia magnates decided to illuminate their own city in 1880. Among them were John Wanamaker, textile baron Thomas Dolan, and the banker John Lowber Welsh, who managed the finances of the Reading Railroad. After buying the right to manufacture Brush equipment, in March, 1881, they founded the Brush Electric Light Company of Philadelphia. Their first project was to light Chestnut Street from river to river, "bright enough for a man to read a newspaper."* (Vidumsky, 2012)

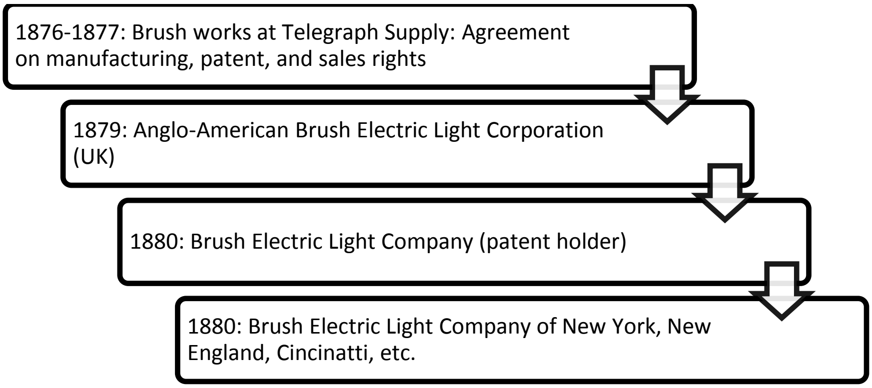

Figure 61: Successive companies of Charles Brush.

Between 1881 and 1895, more than twenty small local electric companies sprang up in Philadelphia alone, operating at a number of different frequencies and voltages. This period of struggling for political, legal, and financial supremacy was brought to an end in 1902 by the consolidation of all the small companies into the Philadelphia Electric Company, with the right to operate in the whole city of Philadelphia (Wainwright, 1961).

In the meantime Brush also expanded into Europe. Again to quote the article in the *Scientific American*:

> *It has made wonderful advances in England, where it is controlled by the Anglo-American Brush Electric Light Corporation, Limited, having a capital of $4,000,000. One year ago this company bought the English patents of Mr. Brush at a very large price, and we understand they have recently purchased all his other foreign patents—those for France, Belgium, Austria, Russia, Italy, Spain, Norway, Sweden, Denmark, etc., paying for them still larger prices than they paid for the English patents, and they now propose to commence the introduction of the Brush light into all these countries in the same business-like*

> *and thorough manner which has characterized its management from the first. The sums paid for these foreign patents are, it is claimed, greater than have ever been paid for any other foreign patents obtained by an American.*("The Brush Electric Light," 1881)

By 1881 the Brush system of dynamo/arc lamps dominated the market.

> *The Brush Electric Light is practically the sole occupant of the field; at least forty-nine out of every fifty lights that have been sold in this country being Brush lights. Up to the present time over 6,000 Brush lights have been sold for regular industrial use, and the business has only just opened. An idea of the great superiority of the Brush system of lighting may be obtained from the fact that with the largest sized Brush machine forty powerful electric lights are burned in one circuit, with an absorption in the machine of thirty-six horse power. We believe that no other system of lighting can maintain one-fifth of this number of Lights on one circuit; and most are confined to a single light to one machine.* ("The Brush Electric Light," 1881)

However, in the mid-1880s, the company lost its dominance. Competitors utilized the basic process of arc lighting to design and build more and better improvements to the system. Charles Coffin of Thomson-Houston Co. bought *Brush Electric* in 1889 and effected a merger with the *Edison General Electric Co.* to organize *General Elec*tric (GE) in 1892. Although GE produced Brush equipment for many years, the Brush Electric works in Cleveland was closed in 1896.

The Brush Bubble (1882)

The demonstrations at the Electrical Exhibition in Paris in 1881 and the Holborn Viaduct in London in 1882 had sparked the interest of the public, not only creating an immense market for the application of incandescent light systems, but also in terms of investing in this new phenomenon:

> *The interest created by the Paris Exhibition and the optimism generated by Holborn Viaduct contributed to heavy speculation in electrical shares in the spring of 1882. Between January 1 and May 13, 1882, British electrical enterprises registered with an authorized capital of £9,000,000*[54]*. During two weeks in May sixteen new companies appeared—the London Economist recalled earlier bubbles in railway shares (1845–46) and the submarine telegraph.* (Hughes, 1962, p. 29).

The sudden surge in electrical development led to overinflated ideas that gas would be replaced by electricity and huge fortunes made, quite unjustified as gas was far cheaper and would be for another thirty years.

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[54] Equivalent to £931 million in 2010 calculated on the basis of historic opportunity costs. Source: http://www.measuringworth.com.

Numerous companies were promoted in 1882, with Charles Brush (1849–1929) leading the way. Among those was the Brush company, floating no less than fourteen subsidiaries. It created a bubble on the stock market when over £7 million was raised by the nascent electricity industry in a manner similar to the Internet bubble over a century later. When the bubble burst, most of the investors lost their money, and after this experience, few investors were found for many years afterward (Spear, 2013b, p. 2).

> *One of the many companies active in England was the Anglo-American Brush Electric Light Corporation (AABC, later named Brush Electrical Engineering Co. Ltd.), founded in 1882 and based in London as a subsidiary of the American Brush Electric Company. This company was created to exploit the patent (U.S. Patent 189.997) of an electric dynamo by Charles Francis Brush (1849–1929). The Brush Electric Company was founded by the equivalent of today's "business angels" (private investors). These wealthy investors, mostly Cleveland's business elite, were connected to Brush through social networks and had a long term perspective. The London AABC, introduced at the stock market, had created a lot of subsidiaries ("little brushes") each receiving territorial exclusivity (for England, colonies and the European continent) to establish central stations and supply lighting. All these companies needed funding and went on the stock market. So AABC became part of a larger speculative bubble in electric company assets in the spring of 1882. In mid-May shares of the Anglo-American Brush Electric Light Corporation dropped £600,000[55] in three days of trading (though they remained above par value).* (Goldfarb, 2010, p. 12)

> *During the spring speculation, the shares of numerous "little Brushes" appeared on the market. Licensed offshoots of "father Brush," these companies, intended to utilize exclusive rights to the Brush lighting system (arc and incandescent) in establishing central stations, caused some concern in conservative circles. The large number of enterprises holding patents of questionable validity but offering licenses and establishing subsidiaries in imitation of Brush caused even greater concern during the spring speculation. From the perspective of year's end the speculation in electrical shares would stand as the chief British security mania of the year.* (Hughes, 1962, p. 30)

One of the results of the bubble was increased legislation in Britain: the Electric Lighting Act of 1882.

[55] Equivalent to £93 million in 2010 calculated on the basis of historic opportunity costs. Source: http://www.measuringworth.com.

Cleveland during the second Industrial Revolution: An early Silicon Valley

Located on Lake Erie at the terminus of the Ohio Canal, Cleveland had long been the commercial centre of north-eastern Ohio. Cleveland's first heavy industrial enterprise, a firm that produced steam furnaces, was founded in the 1830s. Its first iron rolling mills were built in the 1850s, but the city's rise as a manufacturing centre was largely a post-Civil War phenomenon. By the late nineteenth century, Cleveland was not only a centre of production in second industrial revolution industries; it was also a hotbed of patenting. In 1900 it ranked eighth out of all US cities in the total number of patents granted to residents. Many talented individuals took advantage of the period's vibrant market for technology to specialize in the generation of inventions, financing their creative work by selling off the rights to their patents (Lamoreaux, Levenstein, & Sokoloff, 2004, pp. 3-8).

> *Brush himself became a wealthy man, earning royalties on his patents in excess of $200,000*[56] *a year during 1882 and 1883. Indeed, his royalty account accumulated so quickly that the company fell behind on its payments, and to settle the debt, Brush agreed in 1886 to take $500,000*[57] *in stock.* (Lamoreaux et al., 2004, p. 17).

The Brush Electric Company was from early on a magnet for ambitious young men who came to work in its shops, network with other technologically creative people, and catch the eye of investors eager to finance the next Charles Brush. Some of these young men were employees. A range of spin-offs were created: the *Boulton Carbon Company* (later National Carbon), the *Short Electric Railway Company*, the *Lincoln Electric Company*, and the *Cowles Electric Smelting and Aluminum Company*, to name just a few.

> *The entrepreneurs who organized and promoted these new ventures secured investment capital largely by relying on personal connections…The wealthy Clevelanders who bought shares in these new high-tech enterprises seem to have been motivated by the returns they expected to earn from owning and holding them rather than by the profits they could reap by selling them off after an initial run-up in price.* (Lamoreaux et al., 2004, pp. 27-28).

It seemed that Brush Electrical Company played a role comparable with the Hewlett Packard Company more than a century later in the San

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[56] In 2010 that would be more than $4 million (based on the Consumer Price Index calculation). Source: http://www.measuringworth.com/uscompare/ relativevalue.php.
[57] In 2010 that would be more than $10 million (based on the historic opportunity cost using the Gross Domestic Product Deflator calculation). Source: http://www.measuringworth.com/uscompare/ relativevalue.php.

Francisco region called Silicon Valley.

> *In this way, the networks that formed around innovative firms like Brush Electric and White Sewing Machine became engines of local economic development. They encouraged the geographic concentration both of technological creativity and of venture capital. They also matched inventors who had promising ideas with business people who possessed the managerial skills needed to transform these ideas into productive enterprises.* (Lamoreaux et al., 2004, pp. 35-36)

Elihu Thomson and his "electric" business activities

The same pattern of business creation can be seen with the company that would become Thomas Edison's major competitor, the *Thomson-Houston Electric Company*.

It started when in the late 1870s, Elihu Thomson and Edwin Houston began experimenting with and patenting improvements on existing arc lamp and dynamo designs. In 1880 after being approached by Frederick H. Churchill, a lawyer in New Britain, Connecticut, Thomson and Houston agreed to the formation of a company that would engage in the commercial manufacture of lighting systems based on their own patents: the *American Electric Company*. The company paid them $6,000 for their patents and the received stocks in the company. Thomson was given a contract as electrician for two years at an annual salary of $2,500.[58] It was clear that Thomson intended to industrialize his inventions through operations of the *American Electric Co*.[59]

The new company was headed by Thomson for the engineering and technical affairs and Churchill for the business side. However, Churchill committed suicide in December 1880. Next there was conflict about the growth strategy of the firm. Thomson wanted expansion through technical development, but the fifty-seven investors were interested in short-term results. The confrontation ended when Thomson revised his contract and resigned in July 1882. Now American Electric Co. was facing quite a problem, as its major asset was the inventive genius of Elihu Thomson. The investors then sold their stock to the Brush Company. The story, as remembered by Elihu Thomson, goes as follows:

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[58] In 2010 that would be more than $55.000 (based on the historic standard of living calculation). Source: http://www.measuringworth.com/uscompare/ relativevalue.php.
[59] The name of Edward Houston was added to honor his early efforts. Houston did not become involved in the company and preferred to stay a scholar; he became a well-known professor.

> *The next thing I heard was that the New Britain people had sold out to the Brush Company, of Cleveland, Ohio. George W. Stockley, the head of the Brush Company, had bought a majority interest in our stock. I met him in New Britain, and I said, "Mr. Stockley, do you know what you have bought? You have bought a law suit, and you are bound to lose out on it." I said, "Please look at this contract." I pulled out the original contract; "If the business is not carried on with due diligence and the proper expenditure of time and money, the patents revert to the patentees on presentation of their stock." He read it, and said, "I wouldn't have touched it if I had known that was there; I wouldn't have had anything to do with it…*
>
> *That is the time that the Lynn people came along; S. A. Barton, H. A. Pevear who was our first President when we got to Lynn, and C. A. Coffin, about 7 or 8 in all; we called them the "Lynn Syndicate." Their interest in our apparatus came about in this way. A promoter named Edwards H. Goff, had bought one of our little machines of several arc lights capacity, and to interest the public had put it in the basement of a building on Tremont Street, in Boston, and so wired it as to put 2 of the lights outdoors. They were good steady lights, and attracted attention, including that of the gentlemen from Lynn, who said, virtually, "Why can't we get this kind of a Lynn?" Barton wanted it for his store, and the others were also interested. They happened to look at the nameplate of the dynamo as run in Boston, and found this inscription, "Manufactured by the American Electric Company, New Britain, Conn…*
>
> *Silas A. Barton and Henry A. Pevear at once made a trip to New Britain, and there met E. W. Rice, Jr., who showed them our apparatus and system. Mr. Rice told them the whole story of how the business stood, and they said, "Why can't we get into this thing?" He told them that he thought that under proper circumstances I would join hands with them and be very glad. That opened the way for the Lynn people to buy the majority interest in the American Electric Company. In fact, they bought Stockley's stock. I made it clear to them that if they bought Mr. Stockley's interest and carried on the business as we hoped it would be carried on, we would join heartily with them, of course.* (E. Thomson, 1934, pp. 762-763)

Thus, in October 1882 a syndicate of Boston-based investors bought out the investors of American Electric and renamed it as the *Thomson-Houston Electric Company* in April 1883. Thomson received a new five-year contract for $3,000 annually.[60] Next, Henry A. Pevaer became president; Edwin Wilbur Rice Jr., head of manufacturing; and Charles A. Coffin, the vice president (Nishimura, 2011, pp. 46-47). In 1883 they moved to the new factory in Lynn, Massachusetts (Figure 62). As Coffin was strongly attracted

[60] In 2010 that would be more than $67,400 (based on the historic standard of living calculation). Source: http://www.measuringworth.com/uscompare/ relativevalue.php.

by the promising future of electric lighting, Thomson had found his counterpart and investors who were willing to go for the longer term. They were aiming at the application of arc lighting (naval searchlights, street lighting), electro-telegraphic, electro-metallurgic, plating, and so on. And the growth strategy was "merger and acquisition," combined with "technical development." The first part was taken care of by Coffin, and the second part was the responsibility of Elihu Thomson.

Coffin organized his marketing effort and the central-station product strategy. He created a department for the marketing of the specific product groups, like arc lighting, incandescent lighting, or street railways. And he sold the arc-based light systems, by the nature of the design, as part of a central station to the organizers and operators of the new utility companies. But there was always the problem of finance:

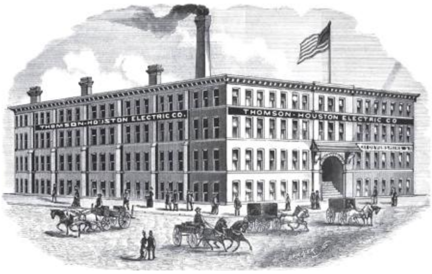


Figure 62: Thomson-Houston Works at Lynn (1884).

Source: http://vintagemachinery.org.

> *One of the most serious problems faced by many fledgling utility companies was raising sufficient capital to pay for equipment. According to one estimate, utilities in the 1880s had to invest between $4 and $8 in plant and equipment for each dollar of sales…Consequently, in building up his sales organization, Coffin was obliged to look for ways to help central stations finance their purchases. As one solution, Coffin had Thomson-Houston accept bonds as partial payment from utilities. Coffin then converted the local utility bonds into capital by organizing a series of trust funds that sold bonds representing local utility securities to Thomson-Houston stockholders. Using this financial innovation, Coffin prevented utility securities (some of which were of little value) from accumulating in the company's treasury, while at the same time generating $2.6 million in capital.* (W. B. Carlson, 1995, p. 63)

Having found a method to finance growth, he used the money to expand the factory in Lynn. But he used the money also to grow by merger and acquisition:

> *Second, Coffin used these funds to buy up smaller rival firms. Between 1888 and 1891, Thomson-Houston spent approximately $4 million to acquire eight electrical companies. Several of these companies, including Brush Electric, Fort Wayne, Schuyler, Excelsior, and Indianapolis Jenney, were competitors in arc lighting; others, such as Van Depoele Electric Manufacturing and Bentley-Knight Electric Railway, were purchased for their street-railway and motor patents. Several of the arc-lighting firms had encountered various problems in*

> *manufacturing and marketing their systems, but Coffin hastened their decline by having Thomson-Houston lawyers vigorously prosecute them for infringement of Thomson's patent for a dynamo regulator.* (Ibid.)

Collins was organizing sales and finance, and Rice manufacturing. This left Thomson to devote his attention to his favourite activity, inventing new products and concepts. For this he created his own laboratory in the Lynn factory, called the *Model Room*.

> *Being a key member of the firm, Thomson considered invention his personal domain, and he actively encouraged the company to make full use of his expertise. Unlike Edison and Westinghouse, who took an active part in the management of their companies, Thomson concentrated on invention and engineering. Having developed a distaste for business matters prior to coming to Lynn, he was content to leave the problems of raising capital and selling lights to Coffin and the Boston office. "I have as little as possible to do with the business of the Company," Thomson explained in 1888, "my work being in the line of development of apparatus and the production of new inventions.* (W. B. Carlson, 1995, pp. 72-73)

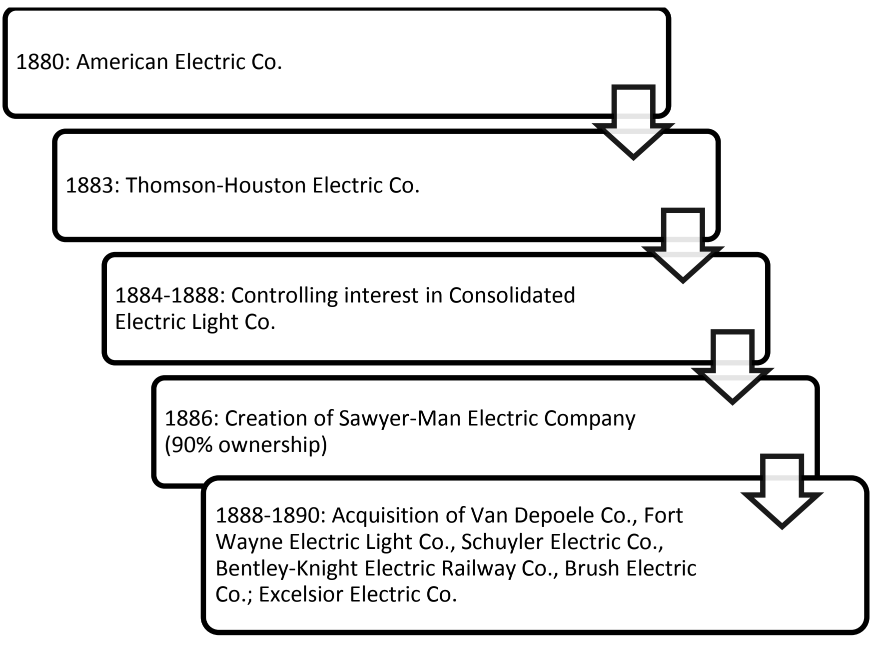


Figure 63: Successive companies related to the work of Elihu Thomson (1880–1890).

Thomson started working on arc lighting and developed a regulator, as the regulation of the distance for the arc between the carbon rods was essential to its functioning. Next came a dynamo, several switches, and other components, and he worked on the system of lighting.

Thomson acquired 310 patents in the period 1879–1892, most of those in the period 1881–1891 (Table 7). As his contract as an electrician to Thomson-Houston did not cover all of his inventions (like the dynamo, system of power transmission, etc.), he was free to develop and sell them. This gave him the autonomy he wanted (Nishimura, 2011, p. 55). Business went well in this period. In Figure 64 the revenues and the profits are shown that were made over this dynamic period between 1883 and 1891.

> *The result of this strategy was a massive growth of Thomson-Houston Electric in the 1880s. The company grew from 45 employees in 1883 to 2422 employees in 1892. In 1891 Thomson-Houston dominated the market of Electric lighting*

Table 7: Overview of some of the patents granted to Elihu Thomson

Patent №	Year	Description
US 250,175	November 29, 1881	Electromagnetic device: Electromagnet to be used in arc light for carbon-rod movement
US 256,605	April 18, 1882	Electric-arc lamp: Feed mechanism for carbon rods
US 258,684	May 30, 1882	Electric-arc lamp: Lamps adapted to dynamos, which are excited by separate currents
US 261,790	July 25, 1882	Electric-arc lamp: Improvement on the drop and lift mechanism
US 272,353	February 13, 1883	Electromagnetic retarding device: Device used in electric arc light
US 281,416	July 17, 1883	Dynamoelectric Machine: Construction of an armature
US 283,167	August 14, 1883	Electric commutator or switch: Interrupting electric currents in arc-light systems
US 297,194	April 22, 1884	Electric-arc lamp: Regulation of the position of the carbons
US 323,976	August 11, 1885	Automatic commutator-adjuster for dynamoelectric machines
US 335,158	February 2, 1886	Incandescent electric lamp: Lamp with incandescent strip or rod
US 335,159	February 2, 1886	System of electric distribution: Application of series-multiple arc systems
US 356,902	February 1, 1887	Armature for dynamoelectric machines
US 363,185	May 7, 1887	Alternating-current electric motor
US 382,336	May 8, 1888	Alternating-current regulator
US 400,971	April 9, 1889	Alternating-current electric motor
US 425,470	April 15 1890	Distribution of electric currents
US 541,345	April 28, 1891	Method of electric welding (issued to the Thomson Electric Welding Company)

Source: USPTO.

central stations: It had sold 669 stations out of the nearly 2000 installed stations (33% market share). Its closest competitors were Brush Electric with 323 stations and Edison Electric with 202 stations (W. B. Carlson, 1995, p. 76). *Besides its electric light business, it entered also other fields of electric application: like the street railway installations. In 1888 Thomson Houston Electric Company acquired the Bentley-Knight, Van Depoele Electric Co. and Sprague patents which gave the company control of virtually all important patents in this field. By the end of 1892 it had sold to 204 companies the motors for 2.769 of street railway cars.* (W. B. Carlson, 1995, p. 66)

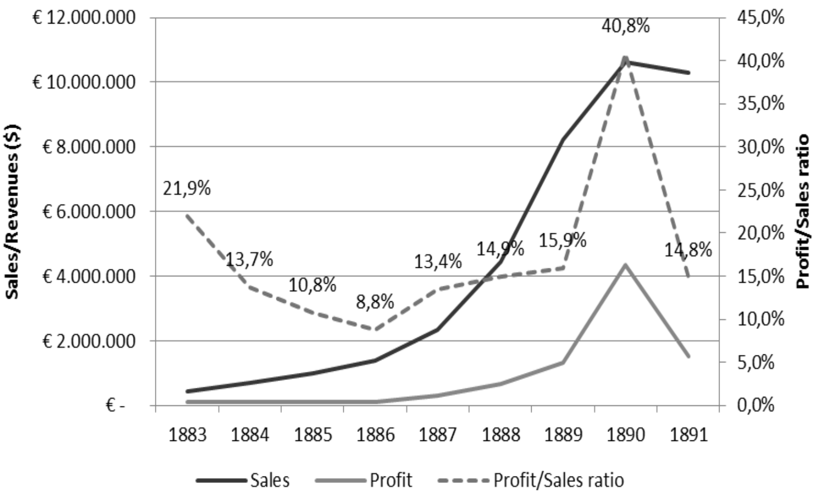


Figure 64: Growth of Thomson-Houston (1883–1891).

Source: (Passer, 1972).

Sebastian Ferranti and his "electric" business activities

In England Sebastian Ferranti struggled creating his successive companies. After his initial company, Ferranti, Thompson and Ince Limited, he continued, struggled, failed, recovered, and finally became more successful in 1890 with Ferranti Ltd. (Figure 65).

He [Sebastian Ferranti] *was actually in the process of developing a novel form of armature at the time that he met Alfred Thompson, a photographer who was also a family friend; and as a result of having interested a solicitor, Francis Ince, in his ideas, the electrical engineering firm of Ferranti, Thompson, and Ince Ltd had been formed by September 1882. Although this new firm survived for only one year—largely because of the severe slump in electric-lighting activity arising from the dubious activities of promoters and engineers during the "Brush Bubble"*

> *in summer 1882—it established the Ferranti name as a significant part of the embryonic industry. In fact, the armature design produced by Ferranti had inadvertently infringed elements of a patent recently taken out by the distinguished scientist Sir William Thomson (later Lord Kelvin), but after agreeing to pay Thomson £500*[61] *a year the firm gained access to a reliable source of technical expertise. Ferranti also worked closely with Robert Hammond, one of the industry's leading entrepreneurs, but although they operated a joint venture between 1883 and 1885, this was no more successful than the first firm. It was only when, in the summer of 1885, Ferranti created a partnership with Francis Ince (based at Hatton Garden, London), that he was able to secure greater continuity in his business activities…*

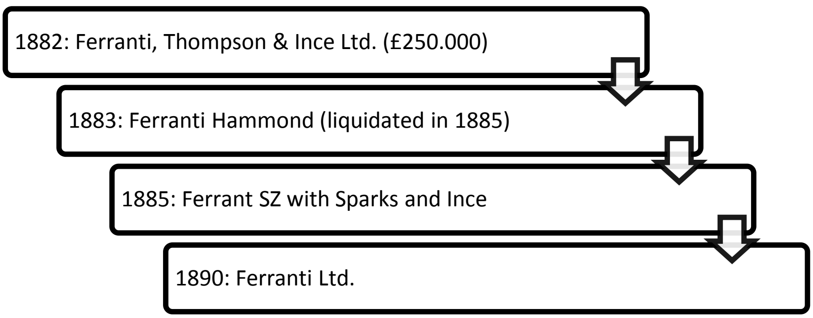


Figure 65: Successive companies created by Ferranti.

> *The infectious enthusiasm for electricity with which Ferranti impressed those around him had certainly been a positive asset up to 1885, but during the next six years it was to be even more important as he launched a series of schemes which would establish his worldwide reputation as a leading advocate of high-tension alternating-current (AC) generation and distribution. It was as a result of selling some of his revolutionary mercury-motor electricity meters to Sir Coutts Lindsay & Co. that Ferranti was to be given the chance to put these ideas into practice, as Coutts Lindsay had ambitious plans to light up London's West End. The firm had first started as a means of lighting Sir Coutts Lindsay's Grosvenor Gallery, but as a result of increased demand from neighbours an extensive system was installed, and advice was given from another member of the Lindsay family, the well-known scientist the earl of Crawford. After the first design failed to work effectively Ferranti was brought in to overhaul the station and distributing system. Experience at the Grosvenor Gallery demonstrated the practical feasibility of Ferranti's ideas, and by 1887 the London Electricity*

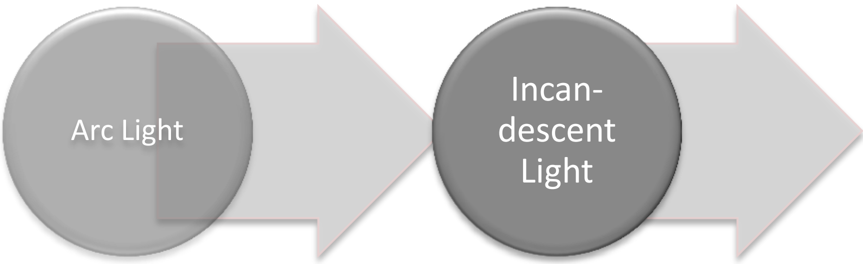
[61] In 2010 that would be more than $40,000 (based on the historic standard of living calculation). Source: www.measuringworth.com/uscompare/relativevalue.php.

> *Supply Corporation (LESCo.) had been created by Lindsay and his brother, Lord Wantage. This venture, designed entirely by Ferranti, was based on an ambitious plan to light two million lamps, using the world's largest generators installed in a much larger station at Deptford. From there, the unprecedented distribution pressure of 10,000 volts would be sent along cables and transformers—a design which challenged contemporary electric current engineering expertise.*[62]

The arc-light applications proved to be the driving force of the early bonanza for manufacturers of electrical (light) systems and their components. They were successful in the market segments for both public lighting and industrial lighting. However, the massive residential lighting market, where electric lighting was in direct competition with gas-lighting, was slow to pick up. Local systems, originally a generator and ten arc lamps, later two hundred arc lamps, were better for public and industrial application, while the later-introduced incandescent lamp proved more suited for residential lighting.

[62] Source: Sebastian Ziani de Ferranti (1864–1930), by Elliott & Fry. http://odnb2.ifactory.com/view/article/33115?&docPos=4&backToResults=list=yes%7Cgroup=yes%7Cfeature=yes%7Caor=8%7CorderField=alpha. (Accessed November 2014)

The invention of the incandescent light



As explained before, the nineteenth century arc lights were noisy and smelly, sparking and hard to regulate, short-lived and expensive to use. They needed a lot of attention and maintenance. But as the phenomenon of creating electric light was quite challenging (everybody wanted this new form of light), the question was how to solve those problems. Improving on details of the arc principle and engineering the product was one method, but could the "voltaic gap" be bridged another way than with a spark? Maybe with a thin wire made out of a precious metal? Or carbon, like the burning of wood, a process that emitted light in a more comfortable way. This idea involved a fundamentally different mechanism. With the arc lamps, it was the ionization of the air between the carbon rods (the "voltaic gap") that created the light. With the wire bridging the "voltaic gap," it was the heated material itself that was emitting light.

Early arc lights were employed in specific situations. The usage of these battery-based arc lights was quite problematic due to the volume, cost, and maintenance of the batteries. The major application of generator-based systems was in street lighting and factory lighting, often one generator for one (or a few) arc lights. But there was another application that was even more challenging: home and office applications. How to bring electric light there?

The application of electric lamps in this kind of environment had specific requirements, like the requirement of using as many lamps as possible on one generator to create a more economically feasible situation. With the generator-based arc light, the problem was how to connect more than one lamp to the generator. Connecting arc lights in parallel was problematic due to the low resistance of the lamp when illuminating, extinguishing the other lamps. Connecting the lamps together in series did not work, as their light emission decreased when another lamp was "switched on." And giving each lamp its own power source did not come cheap. Here, basically, scientists were trying to solve the problem of "subdivision of the electric current" (also called the "subdivision of electric light" or the "divisibility of the electric light") that was manifest in the application of multiple-arc systems. In terms of a description written in 1878 by Hippolyte Fontaine:

> *By the term "divisibility of the electric light" we do not mean the production of several intense lights by means of one machine or battery, but simply the maintaining of a few small luminous centres, each equal to 1 to 15 Carcel burners. It has been proved beyond a doubt that several lamps can be kept in action by one magneto-electric machine, but the question is, whether the first cost and maintenance of such apparatus is not greater than that of a series of small machines each in circuit with a lamp. We have always favoured the latter method of lighting, although the other plan has received a large share of our attention, and there is a likelihood that M. Gramme will still have the honour of making it a practical success. At present, however, the means proposed for attaining this divisibility of the light have been practically without success.*
> (Fontaine, 1878, pp. 185-186)

So, the problem was clear, but finding a solution took some time. It came in small steps, each step leading to the final solution: the vacuumized incandescent lamp with a high-resistance filament.

Incandescent wires bridging the voltaic gap

As early as 1835, James Bowman Lindsay (1799–1862) conceptualized the lightbulb: a light contained in a glass container. Quite a solution, as can be read in the following newspaper article of August 7, 1835:

> *Mr. Lindsay, a teacher in town, formerly lecturer to the Watt Institute, succeeded on the evening of Saturday, July 25, in obtaining a constant electric light. It is upwards of two years since he turned his attention to this subject, but much of that time has been devoted to other avocations. The light in beauty surpasses all others, has no smell, emits no smoke, is incapable of explosion, and not requiring air for combustion can be kept in sealed glass jars. It ignites without the aid of a taper, and seems peculiarly calculated for flax houses, spinning mills, and other places*

> *containing combustible materials. It can be sent to any convenient distance, and the apparatus for producing it can be contained in a common chest.* (Covington, 2013c)

Not too much is known about these efforts, but it is interesting to note that Lindsay was intrigued by the lighting properties resulting from electricity applications.

> *Previous to the discovery of Oersted, I had made many experiments on magnetism, with the view of obtaining from it a motive power. no sooner, however, was I aware of the deflection of the needle and the multiplication of the power of coils of wire than the possibility of power appeared certain, and I commenced a series of experiments in 1832. The power on a small scale was easily obtained, and during these experiments I had a clear view of the application of electricity to telegraphic communication. The light also drew my attention, and I was in a trilemma whether to fix upon the power, the light, or the telegraph.* (Ibid.)

Numerous others explored the "nature of heat," where light was emitted from a hot body (Houston & Kennely, 1896, p. 24), something that could be seen when a (big) battery was, accidentally, connected to a thin cable, resulting in the "voltaic illumination" of the thin wire, sometimes short when the wire burned rapidly, sometimes a little bit longer.

In 1841 Frederick de Moleyn developed a lamp using a "glass globe," in which a platinum wire was placed containing a carbon filament. He obtained the first British patent for an incandescent lamp: GB-Patent №. 9,053, filed on August 21, 1841.

Experiments along this way were conducted by John George Children (1777–1852), Warren de la Rue (1815–1889), and William Robert Grove (1811–1896). Around 1840 these British scientists also experimented with another kind of electric lamp,[63] partly to solve the problem of mine lighting with mine lamps. They

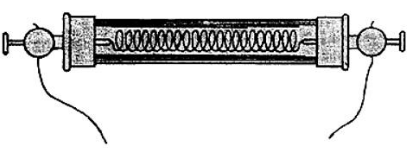


Figure 66: De La Rue's 1820 lamp containing a coil of platinum wire in a vacuum.

Source: The Incandescent Light—A Review of Its Invention and Applications, Floyd A. Lewis, Shorewood Publications, Inc., NY, 1961, pp. 14–15.

[63] In the dark mines, open fire as a source of light was dangerous due to the mine gases. It was, among others like William Reid Clanny, Humphry Davy who created in 1815 a wick lamp with a mesh screen that could be used safely in the mines: the Davy Lamp. Source: Davy, H.: *On the fire-damp of coal mines, and on methods of lighting mines so as to prevent its explosion.* Phil. Trans. Royal Society London. January 1, 1816, p.106 1–22.

enclosed a platinum coil in an evacuated tube (De La Rue, Figure 66) resp. a gas filled tube (Grove) and passed an electric current through it. Robert Grove, professor of Experimental Philosophy at the London Institution, recalled in 1845 (Figure 67):

> *Four or five years ago, soon after publishing the nitric acid battery, I was naturally struck by the facility and constancy with which the voltaic arc could be obtained by that combination, as compared with any previous one, and made several attempts to reduce it to a practical form for the purposes of illumination, but my success was limited…not being able satisfactorily to overcome these difficulties, I abandoned it for the time, and made some experiments on another method of voltaic illumination, which appeared to me more applicable to lighting mines…I substituted the voltaic ignition of a platina wire for the disruptive discharge.*

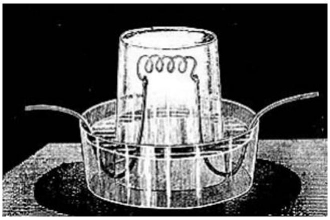


Figure 67: Grove incandescent lamp (1845).

Source: Philosophical Magazine, third serie, vol. xxvii., p. 442. Found in (Pope, 1894, p. 19).

> *Anyone who has seen the common lecture-table experiment of igniting a platina wire by the voltaic current nearly to the point of fusion, will have no doubt of the brilliancy of the light emitted; although inferior to that of the voltaic arc, yet it is too intense for the naked eye to support, and amply sufficient for the miner to work by. My plan was then to ignite a coil of platinum wire as near to the point of fusion as practicable, in a closed vessel of atmospheric air, or other gas, and the following was one of the apparatus which I used for this purpose, and by the light of which I have experimented and read for hours:—A coil of platinum wire is attached to two copper wires, the lower parts of which, or those most distant from the platinum, are well-varnished; these are fixed erect in a glass of distilled water, and another cylindrical glass closed at the upper end is inverted over them, so that its open mouth rests on the bottom of the former glass; the projecting ends of the copper wires are connected with a voltaic battery (two or three pairs of the nitric acid combination), and the ignited wire now gives a steady light, which continues without any alteration or inconvenience as long as the battery continues constant, the length of time being of course dependent upon the quantity of the electrolyte in the battery cells. Instead of making the wires pass through water, they may be fixed to metallic caps wellluted to the necks of a glass globe.* (Grove, 1845, pp. 443, 444)

This description shows the roots of the early development of an incandescent lamp that would become, after much further development efforts, the dominant electric light to be used everywhere—a development that changed society.

Another early experimenter was Professor Moses Farmer of the US Naval Torpedo Station, Newport, Rhode Island. In the article "An Analysis of Some of the Edison Patents for Electric Lighting" in *The Electrician and Electrical Engineer*, Vol. 4, July 1885, the following was stated about him (Figure 68):

Figure 68: Farmer's incandescent lamp (1859).

Source: Covington.

> *Professor Farmer made a great number of experiments, relating not only to the construction of the lamp itself, but to the automatic control and regulation of the current. Among the substances tested for the purpose were aluminum, platinum, iridium, palladium, carbon, etc. Of all the metals, pure iridium was found to give the best results. The next best in order were alloys of iridium and platinum, and of platinum and palladium. Very satisfactory results were also obtained from carbon when enclosed in an atmosphere free from oxygen, as in the Starr lamp…*(Covington, 2013f)

Early inventors of the incandescent lamps

Two elements in these early designs were quite fundamental: the heated wire emitting light and the glass container with vacuum/gas that increased the life span of the wire. The design was based on the concept that the high melting point of platinum would allow it to operate at high temperatures and that the evacuated chamber would contain fewer gas molecules to react with the platinum, improving its longevity. This lamp design was working, but the cost of the precious metal platinum made widespread use problematic.

Now the idea was there, others followed along these lines with their experiments. Others such as the American John W. Starr (1845: carbon filament), Edward Shephard (1850: charcoal filament), Joseph Swan (1850: carbonized paper filaments), and Henrich Göbel (the legend of 1854: carbonized bamboo filament). There were also numerous others, like W. E. Staite (1848), M. J. Roberts (1852, GB-Patent №. 14,198), and Ch. De Changy (1856), who was granted a Belgium patent №. 3,244C on August 28, 1856. However, all their efforts, although resulting in quite a few patents (Table 8) did not result in a reliable, long-lasting, commercially available lamp:

> *None of these incandescent lamps was practical ; they had short lives, were expensive to operate, were unreliable in their operation, and so were not commercially used.* (Howell & Schroeder, 1927, p. 41)

To illustrate the dynamics around the developments of the incandescent lamp, we will highlight some of the important players and their activities in more detail.

Table 8: Some of the British patents granted for early incandescent lights

Patent №	Filed	Patentee	Description
GB 9 053	August 21, 1841	W. Greener; W. E. Straite	Electric light/Incandescent lamp: carbon filament in open glass globe
GB 11 076	February 4, 1846	W. Greener; W. E. Straite	Electric light/Incandescent lamp: Carbon enclosed in airtight transparent vessels
GB 10 919	November 4, 1845	E. A. King (1)	Electric light/Incandescent lamp
GB 12 212	July 12, 1848	W. E. Staite	Galvanic batteries, magnets, application of electricity to lighting and signalising/Incandescent lamps (iridium filament)
GB 13 302	October 24, 1850	E. C. Shephard (2) (F. Nolet)	Electromagnetic apparatus for obtaining motive power, light, and heat/Incandescent lamp
GB 14 198	July 6, 1852	M. J. Roberts	Obtaining light, motion, etv. by the agency of electricity/Incandescent lamp
GB 570	March 7, 1853	J. J. W. Watson	Producing light/Electric light
GB 2 613	November 20, 1855	F. Puls	Obtaining electric light and heat/Electric light

Source: (J. Dredge, 1882),Center for Research Libraries http://dds.crl.edu/loadStream.asp?iid=17444&f=8.
(1): King acted as a patent agent for the Starr patent; see text.
(2) Shepard acted as a patent agent for many inventors, e.g., the Frenchman F. Nolet.

J. W. Starr (1845)

Among those early experimenting scientists was John Wellington Starr (1822?–1846), who experimented with the phenomenon of electricity like the “magneto machine” and the “electric lamp.” From working on the arc light, his attention turned to experimenting with incandescent lamps. He filed at the US Patent Office for a caveat[64] in 1845 concerning a lamp using a rod of carbon operating in vacuum above a column of mercury. His application was rejected in 1846.

[64] Caveats were preliminary descriptions of inventions, less rigorously prescribed than a patent application. They provided temporary protection and required the Patent Office to notify the inventor in the event of a competing patent application, at which point the inventor could file a formal application. Because the invention did not have to be reduced to practice for a caveat, an inventor could describe work that was still at the experimental stage.

Not much is known about him, but in the January 18, 1879, *Scientific American* article "Early history of the electric light," the following narrative appeared:

> *Starr was a maker of philosophical instruments, and resided at Cincinnati. Had he lived he might have proved as much of a genius as Edison. He experimented on his invention, and went to England to complete it, Mr. King going as his agent, and two gentlemen, Judge J. W. McCorkle, late member of Congress from California, and Mr. P. P. Love, of Dayton, Ohio, furnished the money, about $3,000[65]. Each was to have a fourth interest in the invention. Letters of introduction were given to King and Starr to the American banker in London, George Peabody, who, when the subject was fully explained to him, agreed to furnish all the capital that would be required to promote the project to a successful and practical use, provided that the same was approved and sanctioned by the best and most celebrated electricians in Europe. Professor [Michael] Faraday was chosen…In the meantime Starr and King returned to Manchester, where Starr built what he termed a tree, called "The United States." He had on it twenty-six branches or limbs, which he called by the names of the then twenty-six States of the Union. At the end of each limb he had an electric light, covered by a glass globe, on each of which was painted or inscribed the name of each State. Having thus completed his invention, he and King took it to London and exhibited it to the electricians at the Electrical Society, Professor Faraday being present. So perfect was his invention that the Professor pronounced it a perfect success.* (Scientific American, January 18th, 1879)

His English success was short, though.

> *After the exhibition was over King and Starr went home perfectly elated with the success, and after partaking of a very frugal meal they retired to bed. The next morning Starr, not making his appearance at the morning meal, was allowed to remain in bed, but as the day advanced and he did not make his appearance, King and the landlord went to his room, and not being able to awaken him, they burst open the door, and there found poor Starr dead in*

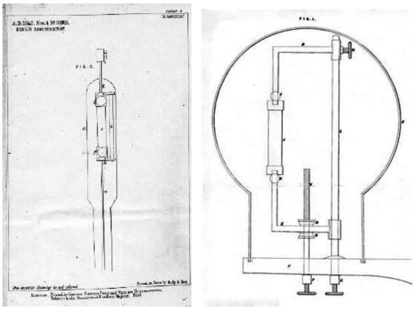


Figure 69: Starr-King GB patent: Upper part of mercury-containing vessel (top) and incandescent wire (bottom) (1845).

Source: http://www.radiomuseum.org (left), Covington (right).

[65] About $ 64,000 in 2010 (based on labor cost). Source: www.measuringworth.com

his bed. The excitement and overwork of the brain are supposed to have caused his death. From that day to this nothing further has been done with the Starr invention. (Covington, 2013d)

It was his attorney, Edward Augustin King, who applied for a British patent (Figure 69). It was granted in Scotland and England: Letters Patent granted for Scotland, November 26, 1845, and enrolled March 25, 1846; English Patent sealed November 4, 1845.

Starr suggested, in his English patent №. 10,919, granted November 4, 1845, two forms of small incandescent electric lamps, one having a burner made from platinum foil placed under a glass cover without excluding the air, and the other composed of a thin plate or pencil of carbon enclosed in a Torricellian vacuum, "which claims the use of continuous metallic and carbon conductors, intensely heated by the passage of a current of electricity, for the purpose of illumination." But as he died early, his contributions were lost in the fog of history[66] (Covington, 2013d).

Henry Goebel (1854)

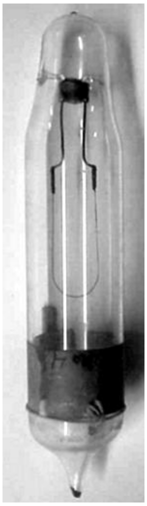


Figure 70: Goebel's incandescent lamp (1852).

Source: Collection of The Henry Ford.

Joseph Heinrich Göbel, born in 1818 near Hannover in the Kingdom of Hannover, Germany, was educated as a watchmaker and optician in Germany. He immigrated to America in 1849. And there in New York, he opened the Jewelry, Horology and Optician's Store.

In 1881 Henry Goebel (as he was called later) worked in an advising capacity for the American Light Company, as they needed precision mechanics for the construction of electric lamps. He did not stay involved long as he started his own business in the field of incandescent lightbulbs together with his friend John Kulenkamp. Goebel and Kulenkamp themselves were not successful in starting a business. As a result of his experimenting, however, Henry Goebel was granted three US patents, among them, US patent №. 266,358 for an electric incandescent lamp that was granted on October 24, 1882 (Figure 71). This patent consisted of a method of attaching a filament to lead wires in a lamp. In 1882 Goebel made an offer to sell his inventions to the Edison Electric Light Co. for a few thousand dollars, but Edison did not see enough merit in the invention to accept the offer.

66 Wrege, Charles D. "J. W. Starr: Cincinnati's Forgotten Genius," *Cincinnati Historical Society Bulletin 34* (Summer 1976), pp.102–120 (not verified).

Then came the litigation case originating from Edison in which Goebel played an important role. The year 1893 was one that is remembered for several reasons. The United States was in a financial panic, President Grover Cleveland began his second term in the White House, and the Columbian Exposition (Chicago's World Fair) opened in May of that year. In addition, the incandescent lamp industry was in the throes of patent litigations, brought about mainly by the Edison Electric Light Company.

In that context came the alleged infringement that involved Henry Goebel's invention. Goebel claimed that he had already invented as early as 1854 the electric lamp in the version that Edison patented in 1880 (Figure 70). This claim, which became known as the "Goebel Legend," was related to the fact that Edison filed suit against companies that were supposed to infringe on his patent. Among these were the *Beacon Vacuum Pump and Electrical Company* from Boston, the *Columbia Incandescent Lamp Company* from St. Louis, and the *Electric Manufacturing Company* from Oconto, Wisconsin. The defense of these companies, who could not expect much success when a basic patent was the issue, used the existence of a prior invention (called "overseen invention"[67]) to support their case. They (thought they) found it in Goebel's work on incandescent lamps. This became known later as the "Goebel Defense" (Covington, 2013g).

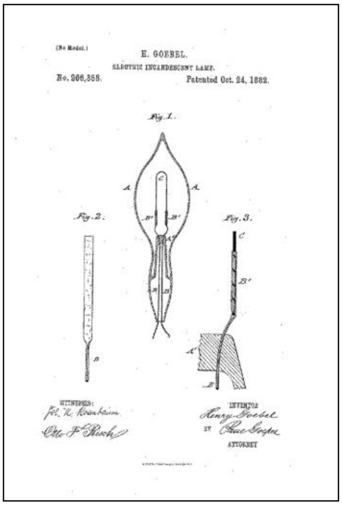


Figure 71: Goebel's patent 266,358 for an incandescent lamp (1882).

Source: USPTO.

In their rulings two judges expressed their judgments. Judge Colt declared in Edison Electric Light versus Beacon that Goebel's claim was unjustified: "It is extremely improbable that Henry Goebel constructed a practical incandescent lamp in 1854" ("Edison Electrlc Light Co. V. Beacon Vacuum Pump & Electrical Co. et al.," 1893, p. 690). Judge Hallett stated in Edison Electric Light versus Columbia Incandescent Lamp Co., St. Louis otherwise: "It is not reasonable to believe that he [Goebel] made the story related in his affidavit, and did not make the lamp he has described" ("Edison Electric Light V. Columbia Incandescent Lamp.Co. et al," 1893, p. 497).

67 Expression used in: Franklin Leonard Pope: The Carbon Filament Lamp of 1859—The Story of an Overlooked Invention. In: The Electrical Engineer, Vol. XV, No. 247, January 25, 1893, p. 77 (not verified).

A decision, whether the Goebel anticipation was held true or untrue, required a final hearing, but there was never a final hearing in the litigations using the Goebel defense. It was the responsibility of the Edison Electric Light Co. to move the case in St. Louis to a final hearing. Probably they did not because of the (forced) expiry date of Edison's patent in 1894 and the high cost.

> *The basic filament patent granted to Thomas Edison that was at issue in much litigation, was №. 223,898, dated January 27th, 1880. Ordinarily such a patent would have been in effect for 17 years, but a ruling existed which stated that a patent would expire at an earlier time if a foreign patent on the same invention were to expire before the normal period of 17 years passed.*[68] *As it happened, a similar patent was granted in Canada on november 19th, 1879; that patent expired november 19, 1894. The Edison U.S. patent №. 223,898 therefore expired on that same date, november 19th, 1894.*
> (Covington, 2013g)

The litigation case aside, however, it is highly improbable that Goebel did discover as early as 1854 an incandescent lamp, as investigated by Rohde in 2007 (Rohde, 2007), who concluded:

> *A thorough review of all affidavits in related suits available for inspection in U. S. archives confirms that Goebel's story is not tenable; it was fraudulent. In 1882, Goebel had already used his pretension for reasons of advertisement for his own business. In 1893, three companies that were producing incandescent lamps without license tried to use Goebel's story to defend preliminary injunctions brought against them by the Edison Electric Light Company. In one case, a judge refused the preliminary injunction asked for, but this fact does not prove the truth of Goebel's story. In Germany, however, reports on those suits in American technical papers were misunderstood, and in the 1920s the legend arose that Heinrich Göbel, a man of true German spirit and blood, was the real inventor of the incandescent lamp. The story was particularly popular during the years of the Nazi regime, but it was retold and believed up to the beginning of the 21st century.* [69]

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[68] Section 4887 of the Revised Statutes of the United States says: "Every patent granted for an invention which has been previously patented in a foreign country shall be so limited as to expire at the same time with the foreign patent, or, if there 'be more than one, at the same time with the one having the shortest term, and in no case shall it be in force for more than seventeen years'" (Pope, 1894, p. 75).

[69] Source: The Goebel Legend. http://home.frognet.net/~ejcov/rohde.html. (Accessed November 2014)

Later development of the incandescent lamp before Edison

In the decade before Edison made his discovery, numerous others were experimenting with the principle of creating electrical light by using a filament. Among those were the Americans Hiram Maxim (1878) and Moses Farmer (1878) and the Russians Lodyguine (1872), Konn (1875), and Bouliguine (1876) (Schroeder, 1923). (Figure 72)

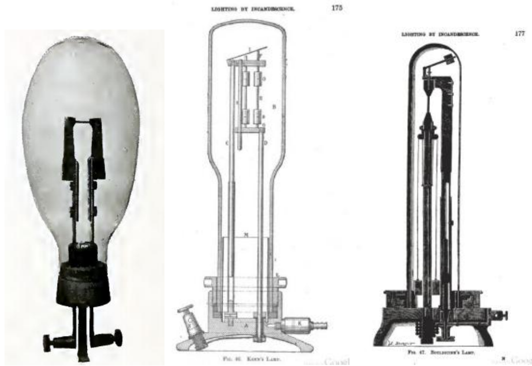

Figure 72: Farmer's incandescent lamp (1878), Konn's lamp (1875), and Bouliguine's lamp (1876).

Source: (Pope, 1894, p. 42) Edwin Hammer, "Incandescent Lamp Development to the Year 1880," Hippolyte Fontaine, Electric lighting: A practical treatise, 1877.

Hiram Maxim (1840–1916), an American inventor who moved to England and became famous for his invention of the machine gun, also worked on the development of the electric lightbulb. They all experimented with the raw material to be used for the vacuum or the gas inserted in the bulb (Swan: carbonized cotton, Maxim: Bristol cardboard, Edison: bamboo, etc.).

> *Farmer made a lamp consisting of a graphite rod which also operated in nitrogen gas. It was covered by a glass bulb having a rubber stopper through which copper rods connecting with the burner passed. A tube was put in the rubber stopper through which the air was exhausted and nitrogen gas put in. Maxim…made two lamps. One consisted of a piece of sheet platinum operating in air. The main feature of this lamp was that when the platinum, held at the top by an adjustable bolt and nut, became too hot and dangerously near its melting temperature, it would expand sufficiently to make contact with a wire which short circuited the burner…The other lamp consisted of a graphite rod operating in rarefied hydrocarbon vapor and protected from excessive current by an electro-magnet which short circuited the graphite burner.* (Howell & Schroeder, 1927, p. 42)

Many—like Hiriam Maxim (Figure 73), Charles Bush, and others—also experimented at the same time with arc lights and created, next to the lamps, also the dynamo. All these activities around the filament to be used in a vacuumized bulb created quite some patent activity in the United States and England in the period 1875–1879 (see Table 9 and Table 10). It all resulted in several different designs, but none of them reached the status of a dominant design. In the next part, we will describe some of the other experimenters and the results of their work in this second phase of the development of the incandescent lamp.

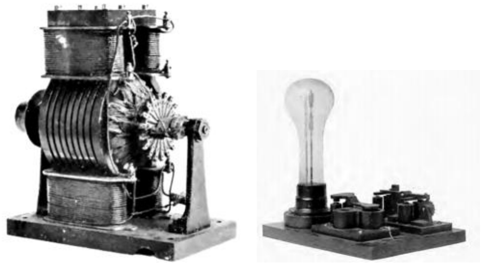

Figure 73: Maxim's dynamo (left) and incandescent, graphite, lamp (1878)/

Source: (Pope, 1894, p. 42).

Table 9: Some US Patents for early incandescent lights before Edison

Patent №	Inventor	Filed on	Granted on
US 166,877	Stephane A. Kosloff***	June 23, 1875	August 17, 1875
US 181,613	H. Woodward**	January 4, 1875	August 29, 1876
US 194,500	William Sawyer	June 22, 1877	August 21, 1877
US 201,175	St. George Lane Fox*	August 31, 1877	March 12, 1878
US 205,144	W. Sawyer & A. Man	May 16, 1878	June 18, 1878
US 212,851	Philip Jenkins	October 22, 1878	March 4, 1879
US 213,643	Moses G. Farmer	November 20, 1878	March 25, 1879
US 214,636	Thomas A. Edison	October 14, 1878	April 22, 1879
US 234,345	Joseph W. Swan*	June 16, 1880	November 9, 1880

* British nationality, ** Canadian nationality, *** French nationality.

Source: USPTO.

Table 10: Some of the British patents granted for early incandescent lights

Patent №	Filed	Patentee
GB 3,809	December 14, 1872	S. W. Konn (A. M. Lodyguine)
GB 3,988	1878	Fox
GB 4,226	1878	Edison
GB 5,306	1878	Edison
GB 4,933	January 2, 1878	Joseph Swan
GB 18	1880	Swan
GB 3,494	August 28, 1880	St. George Lane Fox

Source: (James Dredge, Cooke, O'Reilly, Thompson, & Vivarez, 1882).

Woodward & Evans (1874)

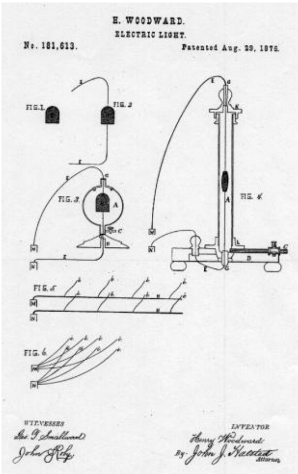

Figure 74: Woodwark/Evans US-patent №. 181,613, August 29, 1876.

Source: www.bouletfermat.com/danny/light_bulb_patent.html, Covington.

The aforementioned experimenters were mainly American. But people were fascinated by the phenomenon of electric light all over the world and also started experimenting, like in Canada:

> *Henry Woodward, a medical student, and Matthew Evans, a hotelkeeper, of Toronto, were neighbors and frequently experimented together with a large Smee battery and induction coil, of which Woodward was the possessor. While seated at dusk one evening watching the buzzer of the induction coil, the light of the spark at the contact post attracted their attention. It impressed them with the idea that if they could confine the spark in a globe a marvelous invention would be the result. From this beginning, in the early part of 1873, Woodward and Evans worked to perfect the idea, and on August 3, 1874, they were granted a Canadian patent [№. 3.738]. The first incandescent lamp was constructed at Morrison's brass foundry in Toronto, and was a very crude affair. It consisted of a water gauge glass with a piece of carbon, filed by hand and drilled at each end, for the electrodes, and hermetically sealed at both ends, having a petcock at one end with a brass tube to exhaust the air…After the invention had been tested a company was formed for the supply of electric lights to the public. Some of the original stockholders had invested capital in the enterprise before having seen the light and when asked to put up more money on the same conditions, declined. Woodward became displeased and left for Europe, and is now said to be residing in London, England. Evans died in Toronto last year* [1899]. (Covington, 2013b)

So Henry Woodward and Matthew Evans were granted CA-Patent №. 3,738 on August 3, 1874, and US-Patent №. 181,613 granted on August 29, 1876: both for a gas-filled lightbulb (Figure 74). Unfortunately, Woodward and Evans were unable to interest investors in their idea. In 1876 Woodward applied for a patent in the United States. Edison saw the concept's potential and in 1879 bought the patent rights from Woodward for US$5,000.[70] Later he also bought a share of the original Canadian patent.

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[70] This (project) amount would be equivalent to more than $700,000 in 2010, calculated on the basis of labor cost. Source: Measuring Worth at http://www.measuringworth.com/uscompare/relativevalue.php.

Sawyer-Man (1877–1878)

William E. Sawyer (1850–1883) was another pioneering experimenter who died early (at the age of thirty-three years). But his case is well known by two facts: his alcoholism and the litigation with Edison's patent. He was born in Brunswick, Maine, and became a telegraphic reporter for the *Boston Post*. In 1875 he moved to New York City and became an electrician for the United States Electric Engine Company, managed by Spencer D. Schuyler.[71] There he worked on telegraphy and was granted numerous telegraphy-related patents in the period 1875–1877. He was discharged in October 1877 due to his conduct—from being an alcoholic (?)—when Hiram Maxim[72] became chief engineer.

> *He* [Schuyler] *had in his employ a large, clumsy, and brutal-looking fellow, clean shaven, whom we call Mr. D. [Sawyer]; he was said to be an expert electrician and telegraph operator, but he was a great drunkard…the first thing I did was to have a talk with Mr. D. I told him that it was not quite the thing to have brandy brought into the place several times a day and to keep on drinking it while at his desk. I assured him that there was a great deal more nourishment in a pint of milk, than in a gallon of brandy, and advised him strongly to try milk. The next day he provide himself with a two-quart pint of milk and his brother was sent out two or three times for milk. Mr. D said that the change was a good one and he felt much better for it. Shortly after I learned that the so-called milk, was just about half brandy, and that the fellow was still in a half-drunken condition all day. As things went from bad to worse I made up my mind that we had better get rid of him.* (Maxim, 1915, pp. 121-122)

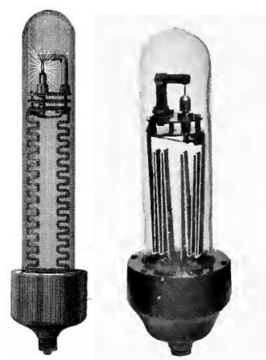


Figure 75: Sawyer-Man's incandescent lamp from US-patent №. 205,144 (left) and in reality (1878).

Source: (Byrn, 1900, p. 71), (Pope, 1894, p. 42).

He had already changed the focus of his experimenting from telegraphy to electric light. On August 14, 1877, he was granted US-Patent №. 194,111 for an "Improvement in Electrical Engineering and Lighting Apparatus and System." It was a patent on a system "to supply electricity to

[71] In 1878 Schuyler created the United States Electric Lighting Company.

[72] Hiram Maxim himself obtained several patents for electric arc lamps (starting with US-patent №. 208,252, September 24, 1878), and claimed that Sawyer stole his ideas: "He thus beat me at the Patent Office and deprived me of a patent that was worth at least a million dollars a year" (Maxim, 1915). Maxim cofounded the United States Electric Lighting Company in 1878.

streets and blocks of a city from a central station for the purposes of electric illumination, electroplating, electric heating, the running of electro-magnetic machines, etc."

This patent was shortly followed on August 28, 1877, by US-Patent №. 194,563 for "Improvement in Electric Light Apparatus." This device—a spark multiplier—was "the construction of induction coil, whereby many such lights may be placed in a single circuit of a galvanic battery or

Table 11: Some early patents granted to William E. Sawyer (resp. with Albon Man) for electric lamps and systems

Patent №	Granted	Description
US 194,111	August 14, 1877	Improvement in electric engineering and lighting apparatus and system: Supply streets, blocks, building in a town with any desired quantity of electricity (filed June 22, 1877)
US 194,500	August 21, 1877	Improvement in electric candles: Considerable number of electric candles in a single circuit (filed June 22, 1877)
US 194,563	August 28, 1877	Improvement in electric lighting apparatus: Combination of multiplier and induction coil for multiple-arc lights (filed June 22, 1877)
US 196,834	November 6, 1877	Improvement in electric engineering and lighting systems: Considerable number of electric candles in the circuit of a single conductor (filed August 10, 1877)
US 205,144	June 18, 1878	Improvement in electric lamps: Incandescent lamp filled with nitrogen gas (filed May 16, 1878, assignee: Albon Man)
US 205,303	June 25, 1878	Electric lighting system: New arrangement of electrical circuits, safety switches, lamps, and lamp-lighting devices (filed May 31, 1878, assignee: Albon Man)
USRE 10134	June 6, 1882	Electric lighting system; reissue of US 205,303
US 205,305	June 25, 1878	Improvement in regulators for electric lights: Electrical regulator adjusting electricity supply to load change (filed May 25, 1878, assignee: Albon Man)
US 210,151	November 19, 1878	Improvement in electric meters: Device to register when a lamp, lamps, or a group of lamps is lighted
US 210,809	December 10, 1878	Improvement in electric lamps: Improvement on patent 205,144, lamp more tasteful in appearance and better adapted to afford a successful electric light
US 211,262	January 7, 1879	Improvement in carbons for electric lights: Process for preparing the illuminating part of an electric lamp…to drive out impurities or occluded gases
US 219,771	September 16, 1879	Improvement in electric lamps/Electric lamps: Incandescent lamp with carbon pencil as filament
US 317,676	May 12, 1885	Electric light: Electric lamps employing an incandescent conductor Enclosed in a transparent hermetically sealed vessel or chamber, from which oxygen is excluded

Source: USPTO.

magnetoelectric machine." US-Patent №. 194,500 was granted for an "electric candle" on August 21, 1877, followed by US-Patent №. 196,834 granted on November 6, 1877, for a system of parallel-connected lamps. Clearly Sawyer was also working on the "division of the electric light." In 1881 he published *Electric lighting by incandescence, and its application to interior illumination* (Sawyer, 1881), in which he paid attention to the division of current and light.

In Table 11 an overview is given of the early patents granted to Sawyer, together with Albon Man. Clearly the cooperation between these totally different persons was, for a certain period, fruitful. How this all happened is quite a story, which unfolded as follows:

> *He came contact with the New York lawyer, Albon Man, and told him "he could make an incandescent or permanent lamp…" Man studied law and was admitted to the Bar of New York in February 1852. In January 1871 he was appointed attorney and counselor to the U.S. Supreme Court. Their meeting resulted in a partnership when Man, greatly impressed with the possibilities of Sawyer's work, and his own interest in the matter, agreed Mr. Man should furnish money to enable Sawyer to complete his inventions.*
>
> *As early as June 1878 three patents were granted to the partners. On June 18th, 1878 they were granted US patent №. 205.144* [Figure 75]*for an electric lamp. Sawyer proposed to make the bottom plate of glass instead of metal, and provided ingenious arrangements for charging the lamp chamber with an atmosphere of pure nitrogen gas which does not support combustion. Patent №. 205.303, issued June 25, 1878, was oriented at improving an electric lighting system. And patent 205.305 of June 25, 1878 was for "improvements in regulators for electric lights." The lamps were arranged in parallel and the regulation of the production of electricity was at its source, the dynamo. This was original conception of the general system for the distribution of light and power from a central station.* (Pope, 1894, p. 12)

As Man sought to interest others in the undertaking, in July 1878, the *Electro-Dynamic Light Company* (ED) was incorporated, in which, in addition to Sawyer and Man, some other persons were investing. That means they paid a small amount ($10,000[73]) of the capitalized sum of $300,000, creating a company operating on a shoestring budget. This new company also acquired the rights to (buy?) the patents of Sawyer and Man for $300,000 in total (Wrege, 1984, pp. 36-37).

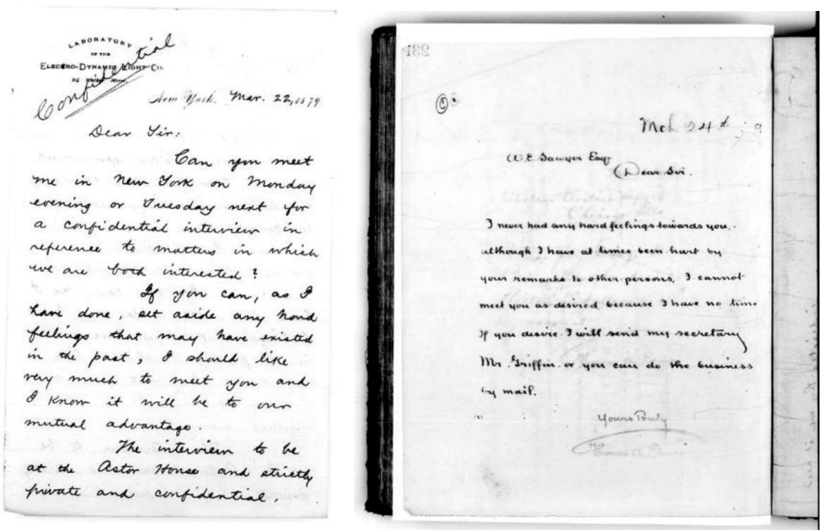
[73] This project amount would be equivalent to more than $2.45 million in 2010, calculated on the basis of labor cost. Source: Measuring Worth at http://www.measuringworth.com/uscompare/relativevalue.php.

This Electro-Dynamic Light Company was soon in financial problems, as they were unable to market the lamps, sell stock, and acquire foreign patents. Man was not too happy about the cooperation with Sawyer:

> *Although I had aided him by suggestions, money and advice up to that time, (he) was in despair about producing a light that would be satisfactory…and said if I would stick with him and help him that the thing could be worked out;…he besought me to stay with him and help him and contrary to my better judgment, I did, and have been sorry for it that I did.* (Wrege, 1984, p. 34)

After several meetings with the board, Sawyer proposed to clean up the problems, but that did not work out. As they failed to sell their lamps, the financial situation became problematic. The workmen were laid off, and Sawyer was allowed by Man to continue working at his own expense. The company got more and more into problems, and by March 1879, Man was so disgusted with Sawyer's behaviour that he declared an end to their collaboration. Sawyer undertook some private actions, like writing a letter to Thomas Edison (Figure 76):

> *On 22 March 1879, two days after making the proposal to solve the problems of Electro-Dynamic, Sawyer (without informing the members of Electro-Dynamic) wrote a letter to Edison asking that the two men join forces, saying that he was*



Confidential

Laboratory of the Electro-Dynamic Light Co.

New York, Mar. 22, 1879

Dear Sir:

Can you meet me in New York on Monday evening or Tuesday next for a confidential interview in reference to matters in which we are both interested?

If you can, as I have done, set aside any hard feelings that may have existed in the past, I should like very much to meet you and I know it will be to our mutual advantage.

The interview to be at the Astor House and strictly private and confidential.

Mch 24th 79

W. E. Sawyer Esq

Dear Sir.

I never had any hard feelings towards you. although I have at times been hurt by your remarks to other persons, I cannot meet you as desired because I have no time. If you desire I will send my secretary Mr. Griffin or you can do the business by mail.

Yours Truly

Figure 76: Correspondence between Edison and Sawyer: on March 22, 1879, request for meeting (left) and on March 24, 1879, declining to meet Sawyer (right).

Source: [D7919] Document File Series—1879: (D-79-19) Electric Light—General. [D7919S; TAEM 50:32]. [LB004] Letterbook Series—General Letterbooks: LB-004 (1878–1879). [LB004231; TAEM 80:66]. Courtesy of Thomas Edison National Historical Park.

> *willing to forget their former disagreements and that his inventions would become the property of the Edison Electric Light Company. Sawyer told Edison he was willing to meet him secretly at the Astor House that evening to talk the proposition over. Edison replied two days later declining to meet him or take him into partnership.* (Wrege, 1984, p. 41)

> *This was not too much appreciated by Sawyer. Sawyer started reacting publically denouncing Edison's effort in the field of telegraphy, telephony, challenging him with a hundred dollar wager to perform eight tasks. One of them was running a carbonized lamp for three hours. Edison did not react. Then Sawyer claimed publically he had invented an incandescent lamp earlier than Edison. "Mr. Edison, over a year ago, began this controversy by an attack upon me. He has received one in return, and evidently does not like it." As Sawyer missed no opportunity to denigrate Edison work, his continued nursing his grudge of one who thought himself underappreciated and his rival overpraised.*
> (Klein, 2010, p. 157)

In the meantime Sawyer had negotiated with the Wallace family to manufacture his lamp. On May 13 he proposed this to the board of the Electro-Dynamic Company. They thus went into an agreement with Thomas Wallace & Sons from Ansonia, Connecticut, to build and sell the ED-lamps for a license fee of $3/lamp. But this did not work out when Sawyer went to Ansonia to start up the production. It took him less than two months to wear out his welcome.

> *Mr. Sawyer's conduct was so bad after going to Ansonia that the Wallaces would have nothing to do with him by the reason of his drunkenness and immorality. They finally came to an open quarrel and Mr. Sawyer returned to New York in September, 1879.* (Wrege, 1984, p. 43)

> *After returning to New York City, Sawyer resigned from the directory of the Electro-Dynamic company and initiated a scheme to form a rival company to compete with Electro-Dynamic: the Eastern Electric Manufacturing Company (EEMC). It was around that time—December 1879—that Edison announced his invention of the incandescent lamp. For his New Year's demonstration, Edison had issued a blanket invitation to electricians'. There, a drunken Sawyer showed up and shouted curses at Edison until the crowd shut him up.*
> (Klein, 2010, p. 157)

A patent speculator, Charles Cheever, aware of all the publicity, then negotiated with Sawyer and Man to file an application for a patent on their behalf (and giving him the option to buy it for $100,000[74] in cash).

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[74] This (project) amount would be equivalent to more than $14.5 million in 2010, calculated on the basis of labor cost. Source: Measuring Worth at http://www.measuringworth.com/uscompare/relativevalue.php.

Therefore a new lamp patent, a replica of the earlier patent with the paper conductors and hard carbon conductors, was filed by Sawyer and Man on January 9, 1880.

The filing of this patent led to an "interference": an investigation into the priority question when two applicants for a patent claim to have originated the same idea. The case *Sawyer & Man v. Edison* was started on September 23, 1880, and was protracted nearly five years. First the decision was rendered in favour of Sawyer & Man. Then, after a motion made by Edison, the case was decided in 1883 again in favour of Sawyer & Man. The Board of Examiners-in-Chief overturned that ruling on appeal on July 28, 1883, awarding priority to Edison. That decision was appealed to the Commissioner of Patents and reversed on October 8, 1883, when Commissioner Marble concluded: "*I think it is fully and clearly shown that Sawyer and Man were the first inventors of the 'incandescent conductor for an electric lamp formed of carbonized paper.'*" Edison appealed and applied for a rehearing, which was denied in 1885. Sawyer and Man were then granted US patent №. 317,676 on May 12, 1885 (Figure 77: US Patent №. 317,676 for incandescent lamp by Sawyer (1885)). But by then Sawyer was already dead by that time.

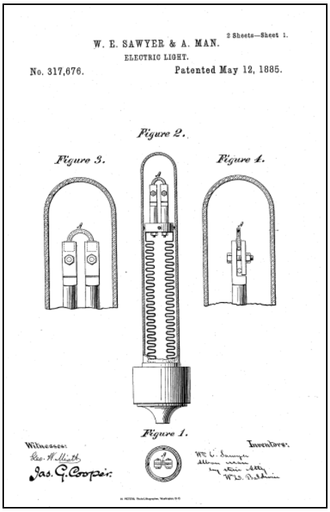

Figure 77: US Patent №. 317,676 for incandescent lamp by Sawyer (1885).

Source: USPTO.

Edison claimed that the outcome was immaterial because he no longer used filaments of carbonized paper, and the broader claims of Sawyer and Man, which would have covered all carbonized fibrous filaments, failed to withstand a long court battle over Edison's carbon-filament lamp patent (his US-Patent №. 223,898)[75] (Pope, 1894, pp. 59-60).

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[75] There were more cases going on in the same time frame. The patent infringement suit against Sawyer and Man—*Edison Electric Light Company v. United States Electric Lighting Company*—was the most important piece of electric light litigation brought by the Edison interests and the only electric light suit initiated prior to 1887…Two contemporary electric light cases—Consolidated Electric Light Company v. McKeesport Light Company (the "McKeesport Case") and Edison Electric Light Company v. Westinghouse, Church, Kerr & Company (the "Trenton Feeder Case").
Source: http://edison.rutgers.edu/NamesSearch/glocpage.php3?gloc=QD&.

> *Despite this new patent [application], Sawyer became more irrational "capricious and utterly unmanageable, and [would] do and say all sorts of foolish and extravagant things…" However, the success of the Edison lamp encouraged Sawyer's new financial backers to form a company to exploit Sawyer's lamps, and, as a result, the Eastern Electric Manufacturing Company (EEMC) with a capital of $2,000,000 was formed in Connecticut on 17 January 1880.* (Wrege, 1984, p. 44)

Sawyer had more and more problems due to his drinking, as well as domestic problems where he was asked by his landlady to leave the house he was living in. He then quarrelled with another boarder, Dr. Theophilus Steele, a former Police Surgeon, over the Edison lamp. Sawyer shot him on April 5, 1880.

> *A difficulty arose between Mr. Sawyer and a Dr. Steele, who boarded at the same place where he lived, which culminated, on the 5th of May, 1880, in an altercation, in which Mr. Sawyer shot Dr. Steele. Mr. Sawyer was arrested, and when the trial took place in March, 1881, he was convicted and sentenced to four years' imprisonment at hard labor. An appeal was made, and as his health was poor, he was permitted to remain at his home pending the appeal. The Court of Appeals affirmed the decision of the Court of General Sessions, and Mr. Sawyer then sought pardon from the governor. As his health was such that his removal was considered dangerous, he was permitted to remain at his house. The District Attorney consented to delay in moving for sentence in one month, which expired May 16, but before the time had expired he received official notice of the death of Mr. Sawyer.*[76]

During the months from April 1880 to April 1881, when he went to trial for the shooting, Sawyer continued to develop new lamps and related equipment (Table 12). As a result two new lamps were patented. US-Patent №. 227,386 was granted on May 11, 1880, patented by Sawyer's father, William Sawyer, similar to Sawyer's previous lamps; and US-Patent №. 241,430 was granted on May 10, 1881, for an incandescent lamp designed to burn in the open air, patented by William Sawyer and Robert Street.

The *Eastern Electric Manufacturing Company*, who had acquired the patents on April 6, 1881, was reorganized into the *Consolidated Electric Light Company* in September 1882. In 1888 the control of the Electro-Dynamic Light Company also passed into the hands of the Consolidated Electric Light Company, which itself was later acquired by the Westinghouse Electric Company of Pittsburg (Pope, 1894, p. 10).

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[76] Source: *Electrical World,* Vol. 1, May 19, 1883, p. 309.

> *In the months between his conviction of shooting Steele in 1881 and the formation of the Consolidated Electric Light Company in September 1881, Sawyer created new problems for EEMC. Although the EEMC officials had provided the money for Sawyer's defense in the Steele trial, Sawyer soon attacked all his benefactors…Sawyer's suits, however, never succeeded and as his health began to fail in 1882, he discontinued his usual attacks against those he believed had wronged him in some manner. Sawyer's health became worse in 1883, and on 15 April 1883, shortly before he was scheduled to be sentenced to prison for shooting Steele, he suddenly died. After his death, his widow announced, on 16 April 1883, that she would soon patent twenty inventions that he had left behind. As a result, on 16 July 1883, the Sawyer-Man Electric Company was formed to exploit these patents. In 1884, the Thompson-Houston Electric Company gained control of Consolidated Electric Company and in 1886, these two companies purchased control of the Sawyer-Man Company.* (Wrege, 1984, p. 46)

His death was the end of a creative and tumultuous period in which his unpredictable character caused difficulties for the various companies with which he was involved during those years. But his legacy created even more as a result of a patent war. What was the case? The Sawyer Man Electric Light Company, owning considerable patents, was, through the quoted acquisitions, in 1888 acquired by Westinghouse. And in the "war of currents" between Thomas Edison and George Westinghouse,[77] these patents were an important asset.

Table 12: Some later patents granted to Sawyer for incandescent lamps and additions

Patent №	Granted	Description
US 227,384	October 12, 1880	Electric lamp: Pencil of carbon heated to incandescence (filed August 31, 1880)
US 227,386	May 11, 1880	Electric lamp: "Stopper lamp" (filed March 26, 1880)
US 229,335	June 29, 1880	Carbon for electric lights: Carbon consolidated and purified by electrically treating it (Electric Dynamic Light Company)
US 229,476	June 29, 1880	Electric switch: Device to regulate the application and division of the current to the lamp
US 241,430	May 10, 1881	Electric lamp: Lamp with two or more carbons (filed December 2, 1880)
US 317,676	May 12, 1885	Electric light: Use of carbonized fibrous or textile material and an arch of horseshoe shape, improvement on patent 205,144

Source: USPTO.

[77] See case study *The invention of the Electromotive Engine.*

Joseph Swan (1878)

Joseph Swan (1828–1914) was born in Sunderland, England from Scottish lineage. At the age of fourteen, he was apprenticed to a pair of druggists. Along with his involvement in chemistry, he also started experimenting with electricity. He learned of Starr's incandescent lamp (he read about his GB patent in the "Repertory of Patent Inventions") and the demonstration of the lamp W. E. Staite developed using an iridium/ platinum wire. They were not the only ones working on the idea of an incandescent lamp. Warren de la Rue had enclosed a coiled platinum filament in a vacuum tube and passed an electric current through it. Fredrick de Moleyns was already granted a patent in 1841 for using a platinum filament within a vacuum bulb (Houston & Kennely, 1896, p. 27). Swan's experiments in the 1848–1855 period involved the creation of carbon filaments, but they did not result in a feasible lamp due to the vacuum problem. This changed when a better Torricellian vacuum pump made by Sprengel became available in 1865. Some twenty years after his first experiments, in 1875, Swan resumed his lamp experiments.

In 1878 he visited the Paris International Exhibition, where he saw public demonstrations of electric-arc lighting. Back in England, together with Charles Stearn, an expert on the Sprengel pump, he continued testing incandescent lamps. Swan made a lamp that worked well for demonstrations, but was impractical in actual use. Swan's burner was made of a thick carbon rod that gave off gases that soon covered the inside of the bulb in soot. Also, the low resistance of the rod meant that the bulb used up too much power.

> *Numerous operational difficulties were encountered, in particular the bulb was obscured by black smoke which suggested that the carbon volatized at high temperature. If so, the lamp would never work. Swan persisted in his view that it would work with a high enough vacuum. The key breakthrough was to continue evacuation when the filament was first incandescent (to drive off occluded gas on the surface) and it was found that carbon in a lamp thus perfectly exhausted and sealed was durable and smoke was not formed. This was perfected in 1878, first publically demonstrated by Swan in Newcastle on 18 December 1878 and further successfully demonstrated before large audiences in 1879…Despite being very patent active Swan did not apply for a patent (unwisely as it turned out) for the bulb per se as he believed it was already well known but he did get patents for key lamp manufacturing features.* (Spear, 2013a, p. 39)

Swan received some patents in 1880 (Table 13), like GB-Patent №. 8, 1880: "*For the treatment of Vacuum in the incandescent lamp*"; and in November 1880, GB-Patent №. 4,933 for the manufacturing features of his incandescent lightbulb with a vacuum in it: the parchmentised threads.

Edison had by then also filed his design for an incandescent lamp: GB-Patent №. 4,576 of October 21, 1879. Swan, in turn, filed for US-Patent №. 234,345, which was granted on November 9, 1880.

Table 13: Some patents granted to Joseph Wilson Swan related to incandescent lamps

Patent №	Filed or Granted*	Description
GB 4,933	January 2, 1878	Electric light/Semi-incandescent lamp: Low resistance filament with parchmentised thread
US 233,445	October 19, 1880	Electric lamp: Incandescence of a continuous conductor of carbon enclosed in an exhausted glass bulb, and provides means for increasing the durability of the said kind of lamp (filed April 12, 1880)
US 234,345	November 9, 1880	Electric lamp: Light is produced by passing an electric current through a conductor of carbon, so as to render it incandescent, said conductor being enclosed in an airtight and vacuous or partially vacuous glass vessel (filed June 16, 1880)
GB 2,272	May 24, 1881	Secondary battery (see US 312,599)
GB 4,202	September 29, 1881	Incandescent electric lamp (see US 260,335).
GB 5,978	? 1881	Incandescent lamp: Filament/threads of squirted nitro-cellulose
US 260,335	June 27, 1882	Incandescent electric lamp: Rendering more perfect than hitherto the contact or connection between the ends of the carbon filaments and the metallic sockets and wires (filed on April 17, 1882)
US 312,599	February 17, 1885	Secondary battery; construction of voltaic piles or batteries, aimed at the production of plates having surfaces more suitable for holding the active material, such as spongy lead or lead in a finely divided form (filed on January 18, 1882)

*) Date for GB-patents is the day the patent was filed
Source: USPTO.

At the Paris Electrical Exhibition of 1881, Swan displayed his bulb lights, and in the same year, 1881, the Swan Electric Light Co. was formed, with a factory in France also. Business was growing rapidly, as electric incandescent lamps were an object of interest for many applications: ships, trains, and buildings. But there did arise a problem, as Edison had a comparable British patent on his incandescent lamp. In 1882 Edison sued Swan for infringement. Although the British press was not too shy about their preference as to whom to give the credit of being the inventor of the incandescent lamp, the problem with the patents was finally solved:

> *British Patents did not have any search and examination before grant at that time so Edison had a patent for the light bulb (probably invalid) while Swan had no patent for the bulb but several for bulb manufacturing (probably valid). In 1882 Edison's company sued Swan's for patent infringement, applied for an injunction to stop Swan manufacturing, and failed. At that point good sense prevailed and they formed a joint company (commonly known as Ediswan) which had all the patents and successfully sued others crowding into the GB market.* (Spear, 2013a, p. 39)

The good sense was certainly stimulated by the fact that Edison lost in the British courts for infringement of Swan's patent. As part of the settlement, Edison was forced to take Swan in as a partner in his British electric works. In 1883 the *Edison-Swan United Electric Lighting Co. Ltd.* was established by the amalgamation of the *Edison Electric Light Co.* and the *Swan Electric Light Co.*, and incorporated on October 26, 1883 (fFigure 78).

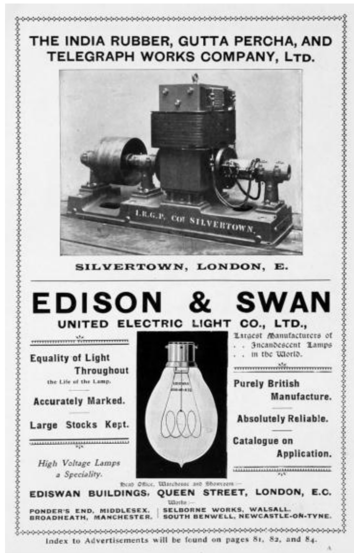

Figure 78: Advertisement for the Edison-Swan incandescent lamp (1899).

Source: www.gracesguide.co.uk/Edison_and_Swan_United_Electric_Light_Co.

Swan became active in America for a short while. He established the *Swan Incandescent Electric Light Company*, of №. 14 White Street, New York City, which was incorporated in 1882 to manufacture and sell incandescent lamps under the patents of Joseph W. Swan. The actual manufacturing was, from 1885 to 1895, carried out by a licensee, the *Swan Lamp Manufacturing Company of Cleveland*, Ohio, which rented space in the Brush factory. As the Cleveland-based Swan Company discontinued business in 1895, the New York-based Swan Company had no income, and the Swan patents expired in the year 1897, the decision to dissolve was made.

Elihu Thomson (1886)

Elihu Thomson and Edward Houston, more or less, were active in arc lamps. The *American Electric Company* (established in 1880 in Lynn, Massachusetts, and later absorbed in *Thompson Houston Electric Co.*) was to sell arc-lamp systems. It became quite successful, dominated the arc-lamp market, and diversified into other electrical markets.

Table 14: Some patents granted to Elihu Thomson for incandescent lamps

Patent №	Granted	Description
US 335,158	February 2, 1886	Incandescent electric lamp: Lamp with incandescent strip or rod (filed on January 2, 1883)
US 336,352	July 12, 1887	Incandescent electric lamp: Lamp with large carbon filaments (filed September 15, 1880)
US 370,993	October 4, 1887	Incandescent electric lamp: Leading-in wires (filed September 15, 1886)
US 462,338	November 3, 1891	Incandescent electric lamp: Lamps for use in series with other incandescent or arc lamps on circuits carrying high tension (filed December 27, 1886)
US 462,339	November 3, 1891	Incandescent electric lamp: Automatic short circuit in case of rupture of the incandescent filament (filed March 12, 1887)

Source: USPTO.

However, by 1884 it was realized that the incandescent lamp was becoming too important to ignore. So, advised by Elihu Thomson of the strengths of Edison's patents, in 1886 they purchased the *Sawyer & Man Electric Co.* and began making incandescent lamps under the Sawyer-Man patents. This activity led to several additional patents for incandescent lamps in the years that followed (Table 14).

The subdivision of light unsolvable?

All these people contributed, in one way or another, to the eventual development of the incandescent lamp, but it was Thomas Alva Edison who put the necessary ingredients together to make the lamp and lighting system practical. The aforementioned efforts resulted in lamps that failed to become of any commercial value, due, among other things, to the brief life of the carbon burner. The platinum-based alternative had the problem that a very slight increase in temperature resulted in the destruction of the wire. So, neither of the two solutions proved to be feasible.

But the problem of "subdivision of light" was bigger than the functioning of the component "electric lamp" itself. This was the problem how to burn several lamps on the same source, each lamp to be operated individually and giving the same amount of light independently of the number of lamps on the source. Many of the scientists of those days declared the problem unsolvable. The Committee of the British House of Commons had, on March 16, 1879, to decide where to spent public funds. Would they continue to stimulate the already existing gas lighting, or would they stimulate the new, still in its infancy, electrical light? Remember, they talked about the arc light, as the newly invented incandescent lamp was not even an issue, especially when William Henry Preece declared in an address to the Royal Society: *"Hence the sub-division of the light is an absolute ignis fatuus."* And Paget Higgs said: *"Much nonsense has been talked in relation to this subject. Some inventors have claimed the power to 'indefinitely divide' the electric current, not knowing or forgetting that such a statement is incompatible with the well-proven law of conservation of energy"* (Dyer & Martin, 1910, p. 86). Time, and Thomas Edison, would prove them to be wrong.

Edison's invention of the incandescent lamp (1879)

It is within this context of many inventors looking at an alternative for the arc light that Thomas Edison (1847–1931) in 1877 became seriously interested in the phenomenon of the glowing wire bridging the voltaic gap. It took place in his recently created Menlo Park research laboratory (Figure 79) (Figure 80).

Figure 79: Edison's research facility at Menlo Park (1880).
Source: http://www.jhalpin.com.

> *In 1876, at the depth of an economic depression, Thomas Edison created a freestanding industrial research facility incorporating both a machine shop and laboratories. It was located in Menlo Park, on the rail line between New York City and Philadelphia. Edison was financially backed by the telegraph company Western Union and Drexel-Morgan financiers like William H. VanderBilt and Eggisto Fabbri (partner of J. P. Morgan). He received about US$130,000*[78] *of venture capital in the two and a half years of active research and development between September 1878 and March 1881.* (McCormick & Israel, 2005, p. 79)

Equipped with resources for experimental development, extraordinary for the time, Edison and a few close associates began twenty months of research, which expanded their well-established accomplishments in telegraphy into pioneering work on the telephone. Edison's ideas and techniques, from telegraph message recording and the telephone, next resulted in his invention of the phonograph, for which he filed the first patent in December 1877 (US-Patent №. 200,521, granted February 19, 1878).

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[78] This (project) amount would be equivalent to $18,500,000.00 (using the unskilled wage) or $30,200,000.00 (using production worker compensation) in 2010, calculated on the basis of labor cost. Source: Measuring Worth at http://www.measuringworth.com/uscompare/relativevalue.php.

Figure 80: Second-floor interior of Edison's research facility at Menlo Park (1880).

Source: http://passionforthepast.blogspot.nl/2012/04/tales-of-everyday-life-in-menlo-park-or.html.

This invention ultimately gave Edison a worldwide reputation—and the nickname "the Wizard of Menlo Park"(Figure 81).

> *Here he continued his work and created his first big financial success, the quadruple telegraph (US patent №. 209.241 granted October 22th, 1878), able to send four telegrams at the same time over one wire. Aside from other material advantages, it is estimated that at least from $15,000,000 to $20,000,000 has been saved by the Edison quadruplex merely in the cost of line construction in America. Edison himself received $30.000[79] for his patent.* (Dyer & Martin, 1910, pp. 58, 60).

Figure 81: The "Wizard of Menlo Park" (1878).

Source: edison.rutgers.edu.

Edison's activities can be characterized as "pyramiding" inventions: one discovery would lead to a cluster of related applications that led to new patentable

[79] This (project) amount would be equivalent to more than $4 million in 2010, calculated on the basis of labor cost. Source: Measuring Worth at http://www.measuringworth.com/uscompare/relativevalue.php.

inventions. Edison already had 269 patents in his nine years of professional inventing, better than one every two weeks (McPartland, 2006, p. 12).

He was, in addition to his more practical orientation, also interested in explaining the existence of a more fundamental principle of nature, an etheric force[80] supporting all the other known forces. Edison became a strong believer in the etheric force "being quite different from electricity," and on January 11, 1876, he published the fruit of his inquiry in a letter to the editors of *Scientific American* entitled "Mr Edison's New Force." This line of thinking certainly placed him among the majority of scientists and technologists of the 1870s, but for the practical-oriented Edison, this was out of line. His exploration of the etheric force was one of the rare times Edison conducted a scientific test without a marketable product in mind (McPartland, 2006, pp. 12-15).

> *The lesson he then [with the lapse in the case of his first patent, the vote recorder] learned was to devote his inventive faculties only to things for which there was a real, genuine demand, and that would subserve the actual necessities of humanity; and it was probably a fortunate circumstance that this lesson was learned at the outset of his career as an inventor. He has never assumed to be a philosopher or "pure scientist."* (Dyer & Martin, 1910, p. 85)

The birth of the incandescent lamp

The era of electric light had begun with the arc light. But arc light was not suited for smaller spaces, like rooms, shops, and offices. So, many creative people looked for alternatives and began experimenting on what would become the "incandescent lamp." Among them was Edison, who was aware of these efforts to create alternatives by using wires to cross the "voltaic gap."

> [Edison] *was convinced, however, that the greatest field of lighting lay in the illumination of houses and other comparatively enclosed areas, to replace the ordinary gas light, rather than in the illumination of streets and other outdoor places by lights of great volume and brilliancy. Dismissing from his mind quickly the commercial impossibility of using arc lights for general indoor illumination, he arrived at the conclusion that an electric lamp giving light by incandescence was the solution of the problem.* (Dyer & Martin, 1910, p. 85)

[80] Later it would be discovered that the high-frequency electromagnetic waves were the basis of their observations and resulting conclusions that a "true unknown force" existed.

It was in 1877 that he started experimenting[81], even though almost the whole scientific world had pronounced the idea of "subdivision of the electric light" impossible. That did not deter Edison. In 1877 Edison had also sold his telephone invention (the carbon transmitter covered by US-Patent №. 222,390 of December 9, 1879) to the Western Union Telegraph Company. Not only did it supply him with finances, but it also gained him experience, as he had now been working with carbon a lot and gained quite some experience with it.

> *It is not surprising, therefore, that in September of that year [1877], when Edison turned his thoughts actively toward electric lighting by incandescence, his early experiments should be in the line of carbon as an illuminant…His originality of method was displayed at the very outset, for one of the first experiments was the bringing to incandescence of a strip of carbon in the open air to ascertain merely how much current was required…Within a few days this was followed by experiments with the same kind of carbon, but in vacuo by means of a hand-worked air-pump. This time the carbon strip burned at incandescence for about eight minutes…Edison also tried hard carbon, wood carbons, and almost every conceivable variety of paper carbon in like manner. With the best vacuum that he could then get by means of the ordinary air-pump, the carbons would last, at the most, only from ten to fifteen minutes in a state of incandescence…After having devoted several months to experimental trials of carbon, at the end of 1878,…he turned his attention to the platinum group of metals and began a series of experiments in which he used chiefly platinum wire and iridium wire, and alloys of refractory metals in the form of wire burners for incandescent lamps…After attaining a high degree of perfection with these lamps, he recognized their impracticable character, and his mind reverted to the opinion he had formed in his early experiments two years before—viz., that carbon had the requisite [high] resistance to permit a very simple conductor to accomplish the object if it could be used in the form of a hair-like "filament," provided the filament itself could be made sufficiently homogeneous.* (Dyer & Martin, 1910, pp. 87-92)

So, after experimenting for a year with metal filaments for his incandescent lamp, Edison turned his attention again to carbon in the fall of 1879. Edison had concluded that bamboo or similar fibrous filaments were more suitable than anything else then known for commercial incandescent lamps, and he wanted the most perfect for that purpose[82]

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[81] One has to realize that the actual work was done by Edison's laboratory assistants, like John Kreusi, a Swiss-trained clockmaker and machine shop foreman; Charles Batchelor, Edison's chief mechanical assistant from England; and Francis Upton, a physicist and mathematician from Princeton University.

[82] Carbonized vegetable fibers made the strongest filaments. As part of a worldwide search, Edison sent William Moore to the Far East. He collected thousands of samples of bamboo

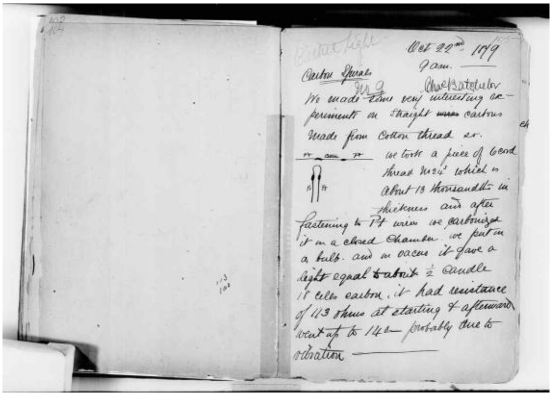

Oct 22nd 1879
9 am.
Chas Batchelor
We made some very interesting ex-
periments on straight carbons
made from cotton thread &c.
we took a piece of cord
thread No 24 which is
about 13 thousandths in
thickness and after
fastening to Pt wires we carbonized
it in a closed chamber we put in
a bulb and in vacuo it gave a
light equal to about ½ candle
it had resistance
of 113 ohms at starting & afterwards
went up to 140 — probably due to
vibration

Figure 82: Carbon as filament (1879).

This is one of the early notebook entries from that work, written on October 22 by Edison's laboratory lieutenant, Charles Batchelor.

Source: http://edison.rutgers.edu. Notebook Series—Menlo Park Notebooks: Notebook #52 N-79-07-31 (1879–1880).

(Figure 82). So, he sent his people out all over the world to find the perfect specimen.

Taking advantage of his financial resources, Edison sent several expeditions to China, Japan, the Amazon Valley, India, and other remote places to find still better fibrous materials. A particular type of Japanese bamboo was found to be most satisfactory, and for many years it was cultivated especially for him by a Japanese farmer. (Bright, 1949, p. 66)

Then came the next step, in which he tried to prevent the burning of the carbon filament: creating a vacuum in the tube.

> *The study of apparatus for obtaining more perfect vacua was unceasingly carried on for Edison realized that in this there lay a potent factor of ultimate success. About August he had obtained a pump that would produce a vacuum up to about the one-hundred-thousandth part of an atmosphere, and sometime during the next month, or beginning of October, had obtained one that would produce a vacuum up to the one-millionth part of an atmosphere…Now, however, that he had found means for obtaining and maintaining high vacua,*[83] *Edison immediately went back to carbon, which from the first he had conceived of as the ideal substance for a burner. His next step proved conclusively the correctness of his old deductions. On October 21, 1879, after many patient trials, he carbonized a piece of cotton sewing-thread bent into a loop or horseshoe form, and had it sealed into a glass globe from which he exhausted the air until a vacuum up to one-millionth of an atmosphere was produced. This lamp, when put on the circuit, lighted up brightly to incandescence and maintained its integrity for over forty hours, and lo! the practical incandescent lamp was born. The impossible, so called, had been attained; subdivision of the electric-light current was made*

to be tested. The best were from a grove in Yawata, near Kyoto, Japan. This became the standard for Edison lamps for the next ten years. See also: Edison letter to William Moore, about 1885. Source: http://americanhistory.si.edu/ lighting/scripts/s19b.htm.

83 Which he patented and was granted on October 18, 1881, in US-Patent №. 248,425.

Figure 83: Edison's incandescent lamp (1879).

Source: www.edison.rutgers.edu/company.htm.

practicable; the goal had been reached; and one of the greatest inventions of the century was completed…This slender, fragile, tenuous thread of brittle carbon, glowing steadily and continuously with a soft light agreeable to the eyes, was the tiny key that opened the door to a world revolutionized in its interior illumination. It was a triumphant vindication of Edison's reasoning powers, his clear perceptions, his insight into possibilities, and his inventive faculty, all of which had already been productive of so many startling, practical, and epoch-making inventions. And now he had stepped over the threshold of a new art which has since become so world-wide in its application as to be an integral part of modern human experience. (Dyer & Martin, 1910, pp. 87-92)

Edison had created, building on the work of others and adding his engineering ingenuity, the incandescent lamp[84] (Figure 83).

That is what Edison invented: a lamp with a high resistance filament of carbon in a vacuum contained in a glass container closed at all points by fusion of the glass and having platinum wires imbedded in the glass to carry current through the glass to the filament. And this was the first incandescent lamp which was suitable for the system of general multiple distribution which solved the problem of the "sub-division of the electric light." (Howell & Schroeder, 1927, p. 60)

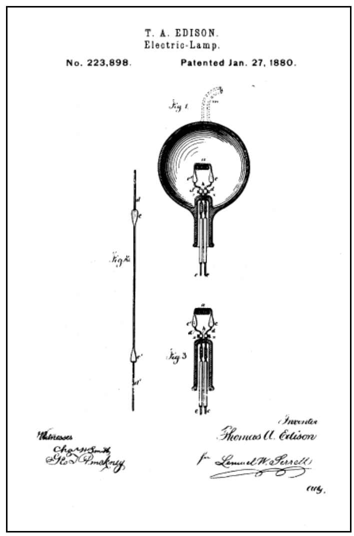


Figure 84: Edison's US-Patent №. 223,898 for an incandescent lamp (1880).

Source: USPTO.

Edison filed for a patent on November 4, 1879, and was granted US-Patent №. 223,898 on January 27, 1880, for his invention (Figure 84). This patent would be the "breakthrough" invention that would be followed by dozens of other patents.[85] It

[84] It would take 125 years after the first marketable incandescent lamps were put on the market before that same lamp would be banned. In 2007 a US bill made the 100-watt bulb obsolete. In Europe the incandescent lamp started to be phased out in 2009. Other, more efficient and less energy-consuming lamps had been developed.

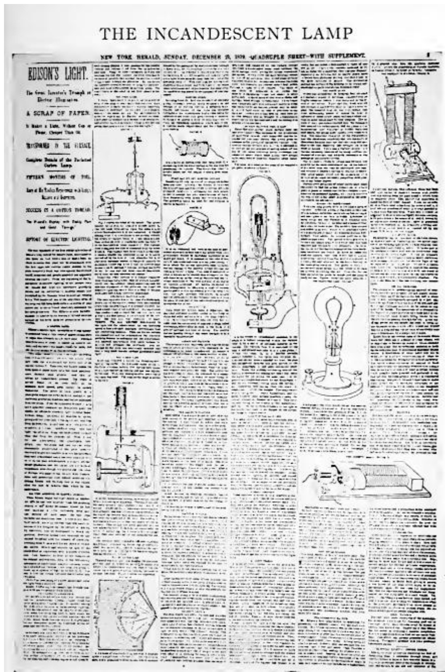
[85] By the way, during his lamp experiments, Edison noticed an electrical phenomenon that became known as the "Edison effect," thermionic emissions that were the basis for vacuum-tube electronics. But that is another story.

was an important patent: “This was ‘the basic patent in the early American incandescent-lamp industry,’ covering the use of a carbon filament as the source of light; it proved to have a profound effect on the industry until it expired” (Merges & Nelson, 1990, p. 885).

That profound effect it indeed had, although in more than one way. It would become the standard for incandescent lamps, but it also resulted in a patent war, destructive competition, and monopolistic behaviour within the new emerging industry.

Demonstrations: Menlo Park, Columbia, and others

In October 1878, after working on the project for only a few months, Edison declared to the newspapers: “I have just solved the problem of the subdivision of the electric light.” This announcement was enough to have an influence on the prices of the stocks of the gas companies (whose lamps supplied the then-current form of lighting). Edison was a little premature, but the damage was done. However, it would take another year to create a functional product (Derganc, 1979; Editor, 1878).


THE INCANDESCENT LAMP

EDISON'S LIGHT.

Figure 85: Announcement in the *New York Herald* of December 21, 1879.

Source: (Howell & Schroeder, 1927, p. 59).

To create public awareness and establish the commercial viability of his efforts, he had to inform the stakeholders and general public. On December 21, 1879, the invention was announced in the *New York Herald* (he leaked the story to *New York Herald* journalist Marshall Fox), and the world was notified of the lightbulb (Figure 85). A demonstration was arranged in Menlo Park.

> *Between October 21, 1879, and December 21, 1879, some hundreds of these paper-carbon lamps had been made and put into actual use, not only in the laboratory, but in the streets and several residences at Menlo Park, New Jersey, causing great excitement and bringing many visitors from far and near. On the latter date a full-page article appeared in the New York Herald which so*

> *intensified the excited feeling that Mr. Edison deemed it advisable to make a public exhibition. On New Year's Eve, 1879, special trains were run to Menlo Park by the Pennsylvania Railroad, and over three thousand persons took advantage of the opportunity to go out there and witness this demonstration for themselves. In this great crowd were many public officials and men of prominence in all walks of life, who were enthusiastic in their praises.* (Dyer & Martin, 1910, pp. 92-93)

The Menlo Park demonstrations (Figure 86) were soon followed by other demonstrations.

> *The first commercial installation was on the steamship Columbia, of the Oregon Railway and Navigation Company. The plant was started May 2, 1880 with 115 lamps, remaining in operation for 15 years without any substantial change. On land, the first commercial installation (1881) was in the lithographing shop of Hinds, Ketchum and Company, 229 Pearl Street, New York…The first public-service station was put into operation at Appleton, Wisconsin, in 1881, and in 1882 central stations were established at Pearl Street in New York; Holborn Viaduct, London; Sudbury, Pennsylvania, and Milan, Italy.* (Usher, 1929, p. 368)

Figure 86: An Edison bulb that was used to light his Menlo Park laboratory (1879).

Source: www.unmuseum.org/lightbulb.htm.

The Pearl Street project was the first large demonstration of the Edison system, in which he demonstrated the possibilities of electric light. The cost of this experiment, including the cost of the buildings, engine, generating machines, and everything, was estimated at from $100,000 to $125,000 (Covington, 2013d). The result of the experiment was the creation of electricity networks to serve private and commercial customers elsewhere, like the Vulcan Street project (1882).

> *H. J. Rogers, president of the Appleton Paper and Pulp Co. and of the Appleton Gas Light Co., initially heard of Edison's plant for his first central station from his friend H. E. Jacobs. Jacobs, a representative of the Western Edison Light Co. of Chicago, described Edison's steam-driven Pearl Street Station in New York City, and Rogers began to envision a water-powered plant along the Fox River in Appleton. Enthusiastically, he convinced A. L. Smith, H. D. Smith, a blast furnace owner; and Charles Beveridge, a banker, to join with him to form the Appleton Edison Light Co.…*

Early operators of Rogers isolated plant encountered many problems and promptly conquered them with much ingenuity. Because of the varying load on the paper mill water beaters, the first generator ran irregularly, causing lights to grow inconsistently dim or bright. The condition was remedied by moving the dynamo to a lean-to off the main office, where it was attached to a separate water wheel. Since there were no voltage regulators, operators used their eyes to gauge the proper brightness for the lamps. Because there was little protection from surges, when storms or falling branches caused short circuits, the plant shut down until the trouble was discovered and corrected. And since there were no meters, customers were charged a flat monthly fee per lamp. In 1882, service was from dusk to dawn, and customers often left their lamps burning all night…

Distribution lines were a bare copper wire. Early house wiring, having a little more protection, was covered with a light insulation of cotton. Wires were fastened to walls with wooden cleats, and tape was wound around wires when they passed through partitions. Early fuse blocks were of wood, and wood was extensively used for sockets and switch handles. ("Vulcan Street Plant," 1882)

There proved to be a large interest in the community for new "scientific" development and the magic phenomenon of the application of electricity. That was also the case at the International Exposition of Electricity held in Paris in 1881 at the Palais de l'Industrie (Figure 87).

Figure 87: Overview of the Exposition Internationale d'Electricité in Paris (1881).

Source: La Nature, 1881, deuxième trimestre, http://cnum.cnam.fr.

> *The scientists and engineers assembled at Paris for the exhibition and for the first International Electrical Congress found themselves a part of an international community dedicated to the advancement of the new technology. For these groups the event was educational, and for the public—especially the financial and commercial sector—the exhibition was a stimulant. Edison, J. Swan, St. George Lane-Fox, and Hiram Maxim, among others, showed the exciting new incandescent lamp; a British electrical engineer wrote "electrical engineering was born at the…Exhibition…a lusty child of science and machinery.* (Hughes, 1962, p. 27)

The public was shown electric light systems (incandescent lamps by Edison, Swan), electric transportation (electric tramway by Siemens, electric cars), the telegraph (Baudot) and telephone (Bell), and batteries and dynamos. Between August 11 and November 20, about 750,000 people visited the exhibition (Borvon, 2009).

The 1881 Paris Electricity Exhibition was an event Edison could not miss participating in, as it was an exhibition to encompass "The Works of Electricians of all ages." Many of Edison's electric-lighting systems, ranging from arc lights to incandescent devices, were exhibited. A model of the Edison central-station lighting system showed an arrangement of incandescent lights within a complete electrical distributing system, including novel appliances and controls of the Edison system.

> *At the exhibition there was a lot of hassling between participating light manufacturers about infringements and the French authorities intervened. It was also the place for industrial espionage: "We frequently find Swan's manager in our place studying our 'processes for lamps.' We shall have to lose no time now or these fellows will steal all we have and use it right under our very nose."* (McPartland, 2006, p. 235).

Edison was present with a big dynamo capable of illuminating 900 lamps at 110 volts. His competitor, Gramme, could only manage ninety-three lights. The exhibition was also a place to do business; it was the moment for business expansion into Europe. This was done through the "Companie Continental Edison," responsible for spin-off electric companies for the European continent. Edison's assistant, Charles Batchelor (1845-1910), did secure French patents and created the "Societe Electrique Edison" at Ivry-sur-Seine for the manufacturing of power plants and also the "Societe Industrielle et Commercialle" to make lamps and sundries. Werner Siemens was offered the license for Edison lighting in Germany, but he declined, putting his gamble on arc lights (Figure 88).

At the show Edison won five gold medals and a Diplome d'Honeur. Batchelor and Lowrey cabled back on the success: "You have distanced all competitors and obtained a diploma of honor the highest award given at the exhibition. …This is a complete success" (McPartland, 2006, p. 237).

Figure 88: Siemens booth at the Electrical Exhibition in Paris (1881).

Source: http://www.theiet.org.

At the same time, England also picked up on the new phenomenon of the electric light:

> *In 1881, Godalming, on the River Wey halfway between London and Portsmouth, became the first town to be lit by electric light (the bid for electricity was £15 less than that for the continuation of gas lighting so economics had a part to play)…On 12 January 1882, Thomas Edison opened the "Edison Electric Light Station" at Holborn Viaduct in London. Six weeks later, the Hammond Electric Light Company opened Brighton power station, which claimed to be the first permanent and viable public power supply. The early applications combined Edison's generator with Watt's reciprocating steam engine.* (Spence & Nash, 2004, p. 93)

Edison, after the success of the Pearl Street station in New York, did the same in England, where the illumination (streetlights, hotels, restaurants, offices, and homes) of the neighbouring district of the Holborn Viaduct station had created great public interest.

> *The English patent-owning company [Edison Electric Light Company of London] established rates for Holborn consumers calculated to create good will and favorable publicity. From April until July, 1882, the station supplied street lighting without charge to the City authorities; for the next six months the rates were the same as gas. Individual arrangements were made with private consumers, but the plan for Holborn kept the price near gas even if it meant no profit. Electricity supplied to customers at rates comparable to gas undoubtedly cost the station at least twice the selling price in 1882. Time would test the wisdom of English Edison's investment in Holborn Viaduct Station, but in the spring of 1882 the station stood as proof of the workability of the Edison system.* (Hughes, 1962, p. 29)

Developments after Edison's discovery (1880)

After Edison's discovery in 1880, he improved on the concept continuously (Figure 89). He tried variations, like the stopper lamp that others were pursuing. For these he was granted US-Patents №. 239,373 (March 29, 1881) and №. 251,543 (December 27, 1881) (Table 15).

Figure 89: Edison lamps improved

From left to right: Edison spearpoint lamp with "Petticoat" press (1880); early Edison lamp with later Johnson bevel-ring base, blue border label (1880); Edison lamp with Johnson bevel-ring base (1881); Edison lamp with hairpin filament (1883); Edison hairpin carbon lamp (1888).

Source: http://www.sparkmuseum.com/lamp_early.htm.

He experimented with the conductors, the sealing, and the vacuum. In total he obtained some 179 patents, 103 and 76, respectively, for lights and dynamos in the 1880-1899 period. Which would mean he got a total of 179, of which 103 were for lights and 76 were for dynamos (R. Thomson, 2011, p. 11).

But Edison was not alone, as other experimenters also developed incandescent lamps. In 1880–1882 these activities resulted in a wealth of

Table 15: Some of the patents granted to Thomas Edison in the 1881–1882 period

Patent №	Granted	Description
US 223,898	January 27, 1880	Electric lamp: High-resistance incandescent lamp to allow practical subdivision of the electric light
US 237,732	February 15, 1881	Electric light: Lamps of hundred candlelight supported by two columns of mercury
US 239,150	March 22, 1881	Electric lamp: Combination of a multiple light system
US 239,373	March 29, 1881	Electric lamp: New method of manufacturing lamps
US 239,745	April 5, 1881	Electric lamp: Lamp with second chamber for conducting wires
US 251,546	December 27, 1881	Electric lamp: Straight high-resistance flexible carbon
US 239,153	March 28, 1881	Electric lamp: Improved support for the carbon filament
US 263,135	August 22, 1882	Electric lamp: Lamp giving a light equivalent to a standard gas-jet, eighteen candle-power

Source: USPTO

Table 16: US patents for incandescent lamps granted after Thomas Edison's '898 patent in the period 1880–1882.

Patent №	Inventor	Filed	Granted
US 223,898	Thomas A. Edison	November 4, 1879	January 27, 1880
US 225,594	John H. Guest	January 9, 1880	March 16, 1880
US 230,953	Miriam S. Maxim	October 4, 1878	August 10, 1880
US 233,445	Joseph W. Swan*	April 12, 1880	October 19, 1880
US 234,345	Joseph W. Swan*	June 16, 1880	November 9, 1880
US 244,277	Miriam S.Maxim	December 8 , 1880	July 12, 1881
US 244,291	Charles G. Perkins	February 4, 1881	July 20, 1881
US 247,097	Joseph Nichols	April 18, 1881	July 20, 1881
US 250,192	Ludwig Böhm	July 15, 1881	November 29, 1881
US 250,227	Edwin M. Fox	May 21, 1881	November 29, 1881
US 251,774	St. George Lane Fox*	June 15, 1881	January 3, 1882
US 255,277	Charles H. Gimingham	December 23, 1881	March 21, 1882
US 258,976	Alex Bernstein	December 24, 1881	June 6, 1882
US 266,358	Henry Goebel	January 23, 1882	October 24, 1882
US 276,571	P. Diehl	December 13, 1882	March 1, 1883

Source: USPTO.
* British nationality.

patents (Table 16), including John. H. Guest, Hiriam S. Maxim, the Brit Joseph W. Swan, Charles G. Perkins, Joseph Nichols, Ludwig Böhm, Edwin M. Fox, St. George Lane Fox, Charles H. Gimingham, Alex Bernstein, and P. Diehl. On June 6, 1882, eight patents for just incandescent lamps were issued to a range of different engineering inventors. Five of those patents were assigned to the United States Electric Lighting Co. (Table 17). Next to these eight we find the patent granted to Charles van de Poele for an invention that was "neither a arc lmp nor an incandescent one" (it was an effort to bridge the "voltaic gap" by powdered carbon).

An early response to the problem of making a better lightbulb was to keep as much of the then-existing incandescent technology as possible and to introduce specific refinements. This could be in the gas used in the bulb and the materials the filaments were made of. Also, they were concerned with improved sealing of leading-in wires and new methods of securing carbon filaments to the platinum leading-in wires.

> *For example, in the two-year period following Edison's patent grant, futile continued attempts to solve carbon renewal problems and challenges arising only in the usage of thick carbon pencils were evidenced by the patent applications of:*

Table 17: Patents granted on June 6, 1882, for incandescent lamps, combinations, and parts

Patent №	Inventor	Filed	Description
Assigned to United States Electric Lighting Co.			
US 258,903A	Moses Farmer	May 27, 1881	Improvement in incandescent lamp: Method of manufacturing a "stopper lamp"
US 258,942A	Joseph V. Nichols	February 1, 1882	Improvement in incandescent lamp: Filament with metal reinforced ends
US 258,943A	Joseph V. Nichols	September 7, 1881	Improvement in incandescent lamp: Shape of filament with reinforced ends
US 258,965A	Edward Weston	December 13, 1881	Improvement in incandescent lamp: Novel form of bracket for use with lamps
US 258,966A	Edward Weston	July 13, 1881	Improvement in incandescent lamp: Better vacuum, increasing durability
Assigned to Inventor or other			
US 258,976	Alex Bernstein	December 24, 1881	Improvement in incandescent lamp: Increase durability and illuminating power
US 259,008A	John Guest	September 12, 1881	Improvement in incandescent lamp: Sealing the globe hermetically
US 259,017	Edwin J. Houston	March 14, 1882	Improvement in incandescent lamp (Assigned to American Electric Company)
US 259,062	Charles J. Van de Poele	February 1, 1882	It will be noticed that my improved lamp is neither an arc lamp nor an incandescent one.

Source: USPTO.

> *Sawyer (US-Patent №. 227,386) for an improved roller contact mechanism for the carbon pencil; Man (US-Patent №. 227,118) for a method of preventing the occurrence of an electrical arc in the carbon pencil-to-conductor connection; Sawyer and Street (US-Patent №. 241,430) for multiple carbon pencils, one of which is renewed in a bath of hydrocarbon while the other is being burned in open air; Farmer of USEL (US-Patent №. 265,790) on shaping thick carbon pencils for open-air operation; Hiram Maxim (US-Patent №. 252,392) for improvements in securing carbon filaments with nuts and screws to leading-in wires; Crosby and Fox (Pat. №. 248,407) for lamp burners made of large carbon sheets; Lane Fox (Pat. №. 251,774) for improved connection between the luminous bridge (burner) and the conducting-wires or terminals; Bohm (Pat. №. 250,192) for a straight carbon pencil connected by spiral conductor, maintaining mechanical tension for improved connection; and McTighe (Pat. №. 258,240) covering a built-in reservoir of hydrocarbon liquid for carbon filament renewal during lamp operation.* (Katznelson & Howells, 2012, p. 13)

Early electric light in Italy: Cruto & Company

An interesting effort to improve upon the incandescent lamp was realized by the Italian Alessandro Cruto (1847–1908). It illustrates the rapid spread of the incandescent filament technology over the continents, as took place in Italy. The young Cruto, an autodidact interested in physics, originally experimenting in an effort to create artificial diamonds, succeeded in producing sheets of graphite from ethylene. He applied this know-how of making pure carbon to create a carbon filament. He did this by depositing carbon on a platinum wire from ethylene under high pressure and temperature. As the platinum would evaporate during the process, it would result in a carbon filament of high purity (Figure 90).

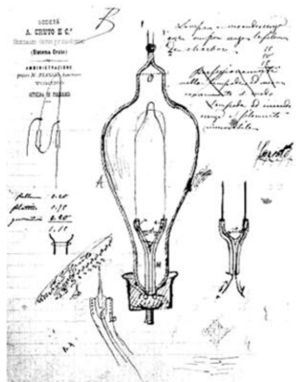


Figure 90: Alessandro Cruto's design for his incandescent lamp (ca. 1882).

Source: Bibliotheca Communale, Alpignano; "Da Cruto a Philips 1886-2003," p. 9.

During his efforts he was stimulated by professor Galileo Ferraris—an inventor of the induction motor[86]—who disputed the viability of Edison's bamboo filament. Then he managed to use Professor Naccari's laboratory at the University of Turin for his experiments. It resulted in a pure carbon filament that gave a bright and white light on September 11, 1880 (Marcoccio, 2003, p. 7) (Figure 91). This was shortly after Edison had filed for a patent on November 4, 1879, and was granted US-Patent №. 223,898 on January 27, 1880, for his invention. As Edison's invention was getting a lot of attention, Cruto's work stayed out of the limelight.

Figure 91: Alessandro Cruto's incandescent lamp (1880–1882).

Courtesy photo (2014): Robert Martynse, ex-president, Philips Italia.

On February 25, 1892, he created a company, *Cruto & Compagnia*, to exploit his inventions. Demonstrating his lamp at expositions in Monaco at Bayern, Vienna, and Turin, he was able to license it to several countries. In 1886 he moved from the small facilities in the city of Piossasco to create a lamp factory, *Societa Italiana di Elettricita Sistema Cruto*, in Alpignano. There he manufactured 1,000 carbon-filament lamps a day, the first to do so in Italy (Marcoccio, 2003, p. 16). He stayed with

[86] See case study *The invention of the Electromotive Engine.*

the company for a couple of years, but then returned to his inventive activities after strong disagreements with the factory's new management. In 1927 the company was, after a bankruptcy, acquired by the then-expanding Philips Gloeilampenfabriek from the Netherlands.[87]

Early electric light in the Netherlands: Philips & Company[88]

The company that in 1912 would be incorporated as Philips Gloeilampenfabriek NV was originally created as Philips & Co. in 1891 by Gerard Philips, the son of Frederik Philips, a quite wealthy tobacco and coffee merchant. Educated at the Poly-Technische School (now the University of Technology) in Delft, the Netherlands, he became fascinated with electricity and studied "electric light" at the Glasgow College of Science in Scotland. He then worked for the Anglo-American Brush Electric Light Corporation Ltd. and realized projects all over Europe. In 1880 he started experimenting with electric incandescent lamps with a carbon filament and started thinking about starting a company.

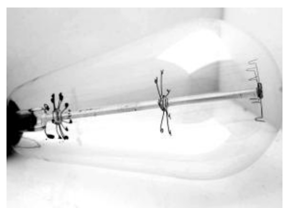


Figure 92: Philips's carbon-filament lamp (above, 1897) and metal-filament lamp (below, 1912).

Source: www.amazefamily.com/vintage-tech-and-breakthrough-bulbs-light-up-the-philips-museum-eindhoven-pictures/; Photos by Luke Westaway.

As the Dutch government did not acknowledge patents, the Netherlands were a popular land to start a company not hindered by patent limitations.

> *After 1886, the best and most vital element in the British incandescent industry departed for the Netherlands, Austria and Switzerland. The Netherlands itself provided a particularly favorable environment because the suspension of the patent law in 1869 had removed all the obstacles to production of incandescent lamps. Knowledgeable and experienced Englishmen set up factories at Middleburg (1889) and Venlo (1889) with money provided by local finance.* [89]

In 1891 the young Philips company was facing quite a bit of competition and managed to grow (1892: 11,000 lamps, 1893: 45,000 and 1894: 75,000) (Figure 92.) As the price erosion through fierce completion dwindled profits,

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[87] Sources: http://www.wikiwand.com/en/Alessandro_Cruto, http://ecomuseo.comune.alpignano.to.it/start.htm.

[88] Text based on: Bekooy, G.: "Philips Honderd (1891–1891)" (publication in Dutch published by the company).

[89] Source: *Bright Lights in the Netherlands.* New Scientist, 11 November 1989. P.63-64

the only way to survive was mass production. In 1898 Philips manufactured a million lamps; in 1900, three million incandescent lamps with a carbon filament. But Philips was facing competition in a more and more regulated market

One has to realize that the carbon filament had its limitations: it was sensitive to shocks, had a limited life span, and was complicated to produce. So in the early twentieth century, new developments in lamp technology resulted in electric incandescent lamps with other metal filaments: the *osmium lamp* (an invention of Carl Ritter Auer von Welsbach in 1900), the expensive *zirconium lamp* (a lamp developed by Walther Nernst around 1902), and the *tantaal lamp* (developed by Drs. Werner von Bolton and Otto Feuerlein of the Siemens-Halske Company in Berlin in 1905). None of these was successful, but the *tungsten lamp* that was developed by the Hungarian Sándor Just and Croatian Franjo Hanaman, who were granted a Hungarian patent (No. 34,541) for a tungsten filament in 1904, created a lamp that was quite efficient, with a good quality of light and a strong filament. It was soon commercially successful in Europe and the United States.

Figure 93: Philips Arga-lamp (75 watt): a metal-filament lamp filled with argon gas (1915).

Source: www.lighting-gallery.net/gallery/displayimage.php?album=2107&pos=50&pid=90482.

Philips also soon created a tungsten lamp and managed to create a production technology in which he could manufacture the filament by using a tungsten powder, sintering it, pressing it into ingots, and extruding it into wire through a diamond die. The resulting wire proved to be strong, and in 1913 Philips introduced its metal-filament lamps, followed in 1915 by the Arga-lamp (a tungsten lamp filled with Argon gas, Figure 93) that performed better than the MAZDA A-lamp made by General Electric, a lamp that was based on a different technology, patented by William Coolidge (US-Patent №. 1,089,933, December 30, 1913). It would become the second-generation tungsten lamp.

In the war period 1914–1918, as Holland stayed neutral, Philips was faced with shortages in the supply and parts from abroad and started to produce them in-house. Philips also started its own research facility, the Nat-Lab, in 1914. After the war Philips expanded and created an industrial network by taking over other (European) manufacturers of electric lamps. One of them was the aforementioned *Societa Italiana di Elettricita Sistema Cruto* in Alpignano.

Other developments in the 1890s

There were others who continued to develop the incandescent lamp (Figure 94). To give just a few examples of lamps developed by others, we mention the following (Covington, 2013a; Katznelson & Howells, 2012; Schroeder, 1923):

Stanley Lamp (1885): It was William Stanley (1858–1916), working for George Westinghouse, who was granted on May 24, 1887, US-Patent №. 363,559 for a strong electric lamp with two filaments.

Poland Lamp (1887): Only ten months after Edison asserted his patent against USEL in 1886, Lawrence N. P. Poland filed in 1887 his patent application; on July 22, 1890, he was issued US-Patent №. 432,710, describing lamp filaments made with iridium.

New Beacon Lamp (1890): Beacon introduced its non-infringing lamp, known as the New Beacon Lamp. Its lamp used a cement material for the stopper and was based on twenty patents issued in the latter half of 1893 to William E. Nickerson and Edward E. Cary.

Pollard Lamp (1892): Edward Pollard filed a patent application on a lamp without leading-in wires (US-Patent №. 485,478). Instead of platinum wires, it utilized powdered silver films fused into the glass as conductors.

In addition to these examples, there were lamps developed like the "New Sunbeam" lamp by the Star Electric Lamp Company in 1893 and the "Novak" lamp in 1894 by the Warren Electrical Company. The incandescent lamp was not only technically a success, but also commercially it proved to be a success. In this period many inventors were active and created their own companies, including:

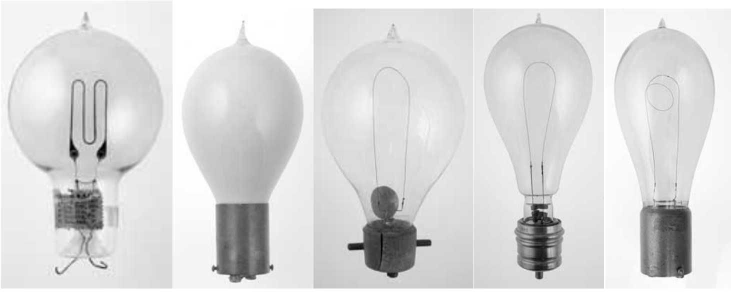

Figure 94: Lamps from other inventors after Edison's lamp

From left to right: Maxim lamp without base (1880); Brush-Swan milk glass with wood base (1885); Woodhouse & Rawson or Stanley with wood base, early 1880's; Beacon stopper with Westinghouse base (1892); Brush-Swan (1885).

Source: www.sparkmuseum.com/lamp_early.htm.

Alexander Bernstein (?): Little is known about the German (?) Alexander Bernstein. From his patent track record, the following can be traced. Living in England (?), he—being a Pimlico engineer—created in August 1885 a company *Bernstein Electric Lamp Company, Limited* to exploit his British Patents № 2604 (1882), № 6075 (1882) and № 3915 (1883). For each lamp produced by the company, Bernstein was to receive a royalty[90]. He had filed on August 3, 1880, for a patent on the manufacturing of incandescent electric-lamp filaments (that was granted as US-Patent №. 369,091 on August 30, 1887). Later, based in Boston in the United States, he was granted US-Patent №. 263,011 on March 16, 1882, for an electric lamp; US-Patent №. 273,704 on March 13, 1883, for an incandescent electric lamp; and US-Patent №. 280,343 on July 3, 1883, for "manufacturing hollow carbons for incandescent lamps." He also received US-Patent №. 319,177 on June 2, 1885, for his design for a holder for his incandescent electric lamp. He developed the low-resistance incandescent lamp and a distribution system to use it, and presented his findings—titled "Electric lighting by means of low-resistance glow lamps" (Bernstein, 1886)—on March 25, 1886, as a foreign member to the Royal Institute of London. In the discussion on house lighting afterward, R. E. B. Crompton participated (A. Bernstein et al., 1886, p. 184). On April 8, 1886, he gave an additional demonstration of his lamps (W. H. Bernstein et al., 1886).

William Crookes (1832–1919): The Englishman William Crookes was a chemist and physicist who discovered the element thalium. Crookes became known for his work on obtaining high vacuum (DeKosky, 1983) and used that knowledge to solve the problems related to incandescent lamps. He obtained several British patents in the period 1881–1883, including: GB-Patent №. 1,422, which was granted on May 31, 1881; GB-Patent №. 2,612, which was granted on June 15, 1881; and GB-Patent №. 3,799, granted on August 31, 1881. The 3,799 patent was also applied for in Austria, Italy, Spain, Denmark, Norway, Sweden, Russia, and the United States (where he was granted US-Patent №. 264,517 on September 19, 1882). Then GB-Patent №. 1,079 was granted on March 6, 1882, and GB-Patent №. 2,185 was granted on April 30, 1883. These patents were for an incandescent lamp with a carbon element enclosed in a vacuous glass vessel. He established a lamp works in Battersea under the management of his son Henry. He wanted to join forces with Edison, who was at that time becoming active in England. However,

[90] Source: The Engineer, August 7, 1885, p.115. http://www.gracesguide.co.uk/images/7/73/ Er18850807.pdf. (Accessed November 2014)

he did not succeed in commercializing all his effort to solve the problems related to creating a functional incandescent lamp. His work on high vacuum was a key in realizing the incandescent lamp, and he was recognized for it at the Paris Electrical Exhibition of 1881. In 1889 he sold some of his patents (№. 2,612, №. 3,799, and №. 1,079) to the Anglo-American Brush Electric Light coco., Ltd., and retired from the field that was dominated by Edison and Swan. But he played an important role as a witness in the case of Edison and Swan versus the Brush Company in 1888 (d'Albe, 2013, pp. 304-310).

Lane Fox (1856–1932): The Englishman St. George William Lane Fox-Pitt worked on incandescent lamps and obtained patents, including GB-Patent №. 3,988 granted on October 9, 1878; GB-Patent №. 1,122 granted on March 20, 1879; GB-Patent №. 3,494 granted on August 28, 1880; and GB-Patent №. 1,543 granted on April 8, 1881. His patent activities started about 1878 and ended about 1883.

The inventor Charles F. Brush entered into the life of Lane-Fox in the year 1880. On Dec 12, 1879, the Anglo American Electric Light Company Limited was formed in England in an effort to acquire the patent rights of Charles Brush. Also, in 1879 this new company bought the patent rights to manufacture Lane-Fox incandescent lamps. However, the company was short-lived. A new company, called the Anglo-American Brush Electric Light Corporation, was formed on Mar 24, 1880. This new company took over the earlier one and then extended its operation. (Covington, 2013a)

As much of the activity went on in the United States and England, some of the later incandescent lamps were invented by European inventors (Schroeder, 1923), such as the following:

Langhans Lamp (1888): In 1888 Rudolf Langhans was working in Germany on substitutes for carbon for lamp filaments. He developed lamp filaments having cores of conductive oxides of earth metals coated with carbon, silicon, boron, or a composition thereof and patented it under US-Patent №. 420,881 granted in February 1890. The same invention was patented in Germany, №. 44,183, dated November 9, 1887; in England, №. 2,438, dated February 18, 1888; in France, №. 188,736, dated February 15, 1888; in Belgium, №. 80,705, dated February 20, 1888; and in Italy, №. 248, Vol. XLV, dated February 21, 1888.

Osmium Lamp (1890): The German scientist Dr. Auer von Welsbach (1858–1929), the inventor of the incandescent mantle around a gaslight: “das Auerlicht,” also created an incandescent electric lamp having a filament of the metal osmium: "das Auer-Oslight." The lamp was patented on March 6, 1906, as US-Patent №. 814,632. The lamps were extremely fragile. Osmium was to be replaced by wolfram. Auer created the company "Osram."

Lodyguine Lamp (1893): The Russian Alexander de Lodyguine, already having invented an incandescent lamp as early as 1872, was hired by Westinghouse to work on coating platinum with other metals for use in incandescent lamp filaments. On January 4, 1893, he filed a patent application that was later issued as US-Patent №. 575,002, covering a process for coating platinum wires with rhodium, iridium, ruthenium, osmium, chromium, molybdenum, and tungsten.

Nernst Lamp: The German Walther Nernst (1864–1941) developed a metal-wire incandescent lamp based on zirconium: the Nernst glower. He obtained US-Patents №. 685,729, 685,730, 685,732 and 685,733 (1901) that were sold to Westinghouse, who created in 1901 the Nernst Lamp Company in Pittsburg. In Europe the lamps were produced by AEG, and at the 1900 World's Fair held in Paris, the pavilion of the AEG was illuminated by eight hundred Nernst lamps. However, as the lamp was expensive, it did not make it in the market, due to the introduction of the cheaper tungsten lamp.

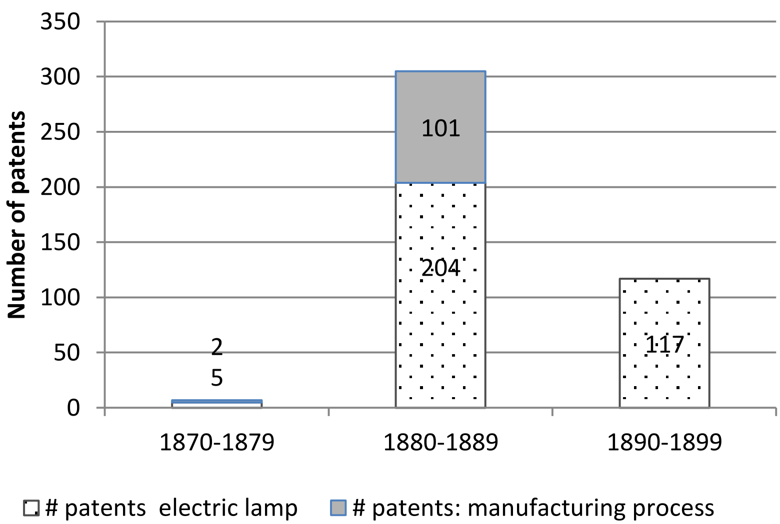

Figure 95: Patenting activity 1870–1899.

Electric lamp classes 313 (apparatus) and 445 (process, method, or instrument for making) in the relevant subclasses therein.

Source: (Katznelson & Howells, 2012, p. 15). Selection based on class selection used in source (appendix A).

The result of all these activities was an increasing number of patents in the 1880s, both for the incandescent lamp and the manufacturing process (Figure 95).

Patent struggles for Edison

The preceding makes it clear that many developments in the field of incandescent lamps were going on. Everybody tried to jump on the bandwagon of electric incandescent light. For Edison the "898" patent proved to be the cornerstone to the further commercial and technical development of his incandescent lamp. As it was the base of a successful implementation, one could be sure his patent was going to be challenged, as it was, for example, by Sawyer and Man.

On January 9, 1880, Sawyer and Man filed for a patent (later granted as US-Patent №. 317,676) in which they claimed the use of carbonized fibrous or textile material (among which was paper) for the incandescent filaments: "We claim as our joint invention: 1. An incandescing conductor for an electric lamp, of carbonized fibrous or textile material and of an arch or horseshoe shape, substantially as hereinbefore set forth…" This part of the patent's broad claim also covered the carbonized bamboo used by Edison, and that was part of his patent claims: "I claim as my invention 1. An electric lamp for giving light by incandescence, consisting of a filament of carbon of high resistance, made as described, and secured to metallic wires, as set forth…" So, Edison's claim on this aspect of the filament material was contested by Sawyer and Man (in the infringement case *Sawyer and Man v. Edison*), with the decisions alternating first in favor of one and then of the other, but which finally resulted in the grant of US-Patent №. 317,676 to Sawyer and Man on May 12, 1885.

> *The Patent Office had declared interference in September 1880 between Edison's application for a patent on an electric lamp with a filament composed of carbonized paper and an application filed by William E. Sawyer (d. 1883) and Albon Man (1826–1905) in January 1880. After a hearing, the Examiner of Interferences awarded priority of invention to Sawyer and Man in January 1882. A second hearing, ordered by the Commissioner of Patents, returned the same decision in June 1883. The Board of Examiners-in-Chief overturned that ruling on appeal on July 28, 1883, awarding priority to Edison. That decision was appealed to the Commissioner of Patents and reversed on October 8, 1883. After additional legal wrangling, U.S. Patent 317,676 was finally granted to Sawyer and Man in May 1885. Edison claimed that the outcome was immaterial because he no longer used filaments of carbonized paper, and the broader claims of Sawyer and Man, which would have covered all carbonized fibrous filaments, failed to withstand a long court battle over Edison's carbon-filament lamp patent (U.S. Patent 223,898).* (Edison, 2013b)

Edison, with his US-Patent №. 223,898, which covered the use of a carbon filament as the source of light, also had a position to defend. The scope of his patent[91] was broad, and a lot of competitors infringed on his patent, including the lamp manufacturers who used the lamp patents of Sawyer-Man, like the US Electric Lighting Co. Edison filed an infringement suit in 1885: *Edison Electric Light Company v. United States Electric Lighting Company*.

> *This infringement suit was initiated by the Edison Electric Light Co. in 1885. The Edison interests claimed that the lamp patents of William E. Sawyer and Albon Man, which had been assigned to the United States Electric Lighting Co., infringed on Edison's patent for lamp filaments (U.S. Patent 223.898). Most of the testimony and exhibits from the 1881 patent interference case, Sawyer and Man v. Edison, were subsequently entered into the record of this case. Other testimony was heard in 1889 and 1890, and the appeal was argued in 1892. Depositions and exhibits from two other cases—Consolidated Electric Light Company v. McKeesport Light Company (the "McKeesport Case") and Edison Electric Light Company v. Westinghouse, Church, Kerr & Company (the "Trenton Feeder Case")—which were initiated at a later date but decided while this case was still being heard, were also entered into the record.* (Edison, 2013a)

Litigation continued for a number of years. Eventually on October 6, 1889, a judge ruled (in the United States Court of Appeals verdict in *Edison Electric Light Company vs. United States Lighting Company*) that Edison's electric light improvement claim for "a filament of carbon of high resistance" was valid. It was a kind of a victory, but a late victory.

Then there was the case *Consolidated Electric Light Company versus the McKeesport Light Company*, which regarded the infringement of US-Patent №. 317,076, issued May 12, 1885, to the Electro-Dynamic Light Company, assignee of Sawyer and Man, for an electric light.

> *The defendants justified under certain patents to Thomas A. Edison, particularly №. 223,898, issued January 27, 1880; denied the novelty and utility of the complainant's patent, and averred that the same had been fraudulently and illegally procured. The real defendant was the Edison Electric Light Company, and the case involved a contest between what are known as the Sawyer and Man and the Edison systems of electric lighting.*[92]

[91] The economic significance of a patent depends on its scope: the broader the scope, the larger the number of competing products and processes that will infringe the patent.
[92] Source: The Incandescent Lamp Patent—159 U.S. 465 (1895), http://supreme.justia.com/cases/federal/us/159/465/.

> *Again, it were the claims made by Sawyer-Man in patent "076" that they had a monopoly of all fibrous and textile materials for incandescent conductors. And that "Edison lamp" as manufactured by the McKeesport Light Company, was using fibrous or textile material covered by their patent 317.076. However their claim was rejected by the Supreme Court. Its decision stated: "If the description be so vague and uncertain that no one can tell, except by independent experiments, how to construct the patented device, the patent is void."* (Merges & Nelson, 1990, p. 850)

All in all, it took a long time (1880–1892) with a lot of legal procedures more or less between Thomas Edison and the successors of William Sawyer (who died in 1883), but in the end Edison got his US-Patent №. 223,898 affirmed. Its relevance as a protective instrument would not last long, however. But despite all these litigation problems, it gave Edison a dominant position in the electric-light industry.

Inventing around Edison's patent

So, Edison's patent position was reaffirmed in the early 1890s. And all those inventors developing incandescent lamps were aware that they had to be careful not to infringe on Edison's Patent №. 232,898. So they tried to develop around Edison's patent, which was reported in an 1893 issue of *Engineering Magazine*:

> *The rigid enforcement of the Edison incandescent-lamp patent by the courts, and the disinclination of the management of the General Electric Company, its present owners, to enter into any arrangement to permit the lamp to be manufactured on a royalty basis by others, has had the effect of stimulating the inventive capacity of the electricians employed by rival interests, with the result that at least two new types of lamp have been put upon the market, which apparently bid fair to be commercially successful, while it is, to say the least, extremely doubtful whether the courts will pronounce either of them to be infringements of the patent (Pope 1893, 96).* (Katznelson & Howells, 2012, p. 16)

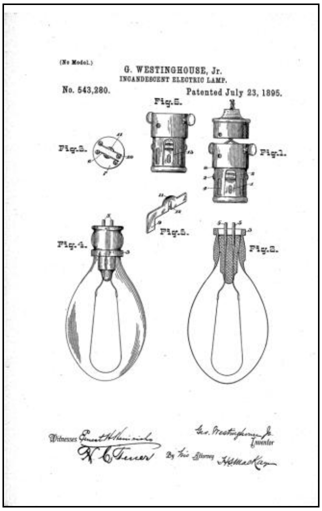

Figure 96: Patent №. 543,280 for Westinghouse Stopper Lamp.

Source: USPTO.

An example would be the "stopper lamp": it was not one all-glass enclosure, but consisted of two pieces. A version of this type of lamp was patented by Westinghouse (US-Patent №. 543,280 filed on August 29, 1892, and granted on July 23, 1895) (Figure 96). Apart from Westinghouse, companies such as Sawyer Man, Packard, and New Beacon, also produced stopper-lamp designs.

> *Already around the time Edison obtained his '898-patent, others were trying to realize an incandescent lamp without infringing on Edison's patent. An example was the incandescent lamp developed by Philip H. Diehl, (1847–1913) who created the "induction incandescent lamp." He managed to evade the patented principle of the "lead-in wires," by using an induction coil in the lamp (US-patents №. s 255.497, granted on March 28th, 1882; №. 272.125 granted on February 13th, 1883; №. 276.571, granted on May 1st, 1883). The '497-patent description stated: "The object of this invention is to furnish an improved electric lamp based on the principle of incandescence, in which the light-giving part of the lamp is enclosed within an evacuated and hermetically-sealed glass globe without any wires passing through the body of the globe to the interior of the same…" It became part of his lighting system (US-patent №. 350.482, granted October 12th, 1886). The lamp was never manufactured commercially, but Westinghouse bought the patent for $25.000.*[93] (Covington, 2013e)

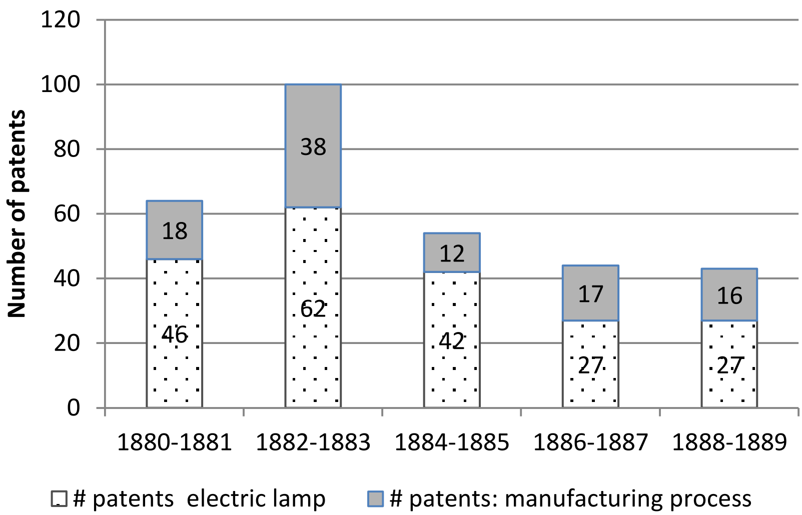

Figure 97: Patenting activity 1880–1890.

Electric lamp classes 313 (apparatus) and 445 (process, method, or instrument for making) in the relevant subclasses therein.

Source: (Katznelson & Howells, 2012, p. 15). Selection based on class selection used in source (appendix A).

[93] This project amount would be equivalent to more than $5.55 million in 2010, calculated on the basis of labor cost. Source: Measuring Worth at http://www.measuringworth.com/uscompare/relativevalue.php.

The period 1880–1890 saw an explosion of patent activities for the incandescent lamp in all its variations (Figure 97). Edison started to get worried about his patent position when there was a surge in the number of patents applied for lamps. In addition to the patents for the incandescent lamps themselves, there were patents for processes, methods, or instruments for making lamps, including patents for a novel glass-globe manufacturing technique, improved sealing of leading-in wires, and new methods of securing carbon filaments to the platinum leading-in wires. His concerns were voiced publicly[94]:

> *However, on October 7th, 1886, the Edison Electric Light Company issued a formal industry open letter from its president Edward H. Johnson…to all electric light station operators in which 8 additional Edison lamp patents and other socket patents were specifically identified as being widely infringed. The open letter also included an alleged infringement analysis of specific lamps made by USEL, Brush-Swan, Bernstein, Mather, Consolidated (Sawyer-Man) and two lamps made by Westinghouse.* (Katznelson & Howells, 2012, p. 16)

Patent war: Edison versus USEL and others

Edison US-Patent №. 223,898, granted in 1880, was annulled in 1883 in the case Sawyer & Man v. Edison. That decision was reversed in 1889 (Consolidated Electric Light Company versus the McKeesport Light Company and Edison Electric Light Company vs. United States Lighting Company). But before that had happened, Edison started in 1885 an infringement case against the United States Electric Lighting Company (USEL), at that time Edison's largest competitor of incandescent lamps. USEL was the owner of the patents from Moses Farmer, Hiram Maxim, Edward Weston, and others (see Table 17).

> *Even though the suit against the United States Electric Lighting Company had been initiated in 1885, it did not finally come to a hearing until 1889. After a long and involved trial, a judgment in favor of Edison was handed down by Judge William Wallace on July 14, 1891, in the Circuit Court of the United States for the Southern District of New York. The defendant had contended that the Edison patent №. 223,898 was invalid because its description of the invention was not adequate, and because other inventors had anticipated the invention. Both of these defenses and the claim of non-infringement were denied…An appeal by the defendant was of no avail. The decision of the lower court was sustained by the Circuit Court of Appeals on October 4, 1892, on virtually the same grounds.* (Bright, 1949, p. 88)

[94] For details, see (Edison Electric Light, 1887)

The court construed the claims based on the specification, in view of the prior art of record. This included the Starr lamp of 1845, the Roberts lamp of 1852, the Lodyguine, Konn, and other lamps which appeared between 1872 and 1876, the Bouliguine lamp of 1877, the Sawyer and Man lamp of 1878, and the Edison platinum lamp of 1879. (Katznelson & Howells, 2012, p. 12)

Edison had, after years of struggling (Figure 98), succeeded in getting a patent for his incandescent lamp; this gave him a legal monopoly using this kind of filament in exhausted and sealed bulbs. But the victory of 1891 creating the monopoly was to be short-lived, as the patent was going to expire in January 1897 (after a seventeen-year term).

Then the management[95] *of General Electric decided a) not to give out licenses to business competitors and b) obtaining injunctions against the producers of competing and infringing lamps. The resulting "rigid" enforcement of the patent*

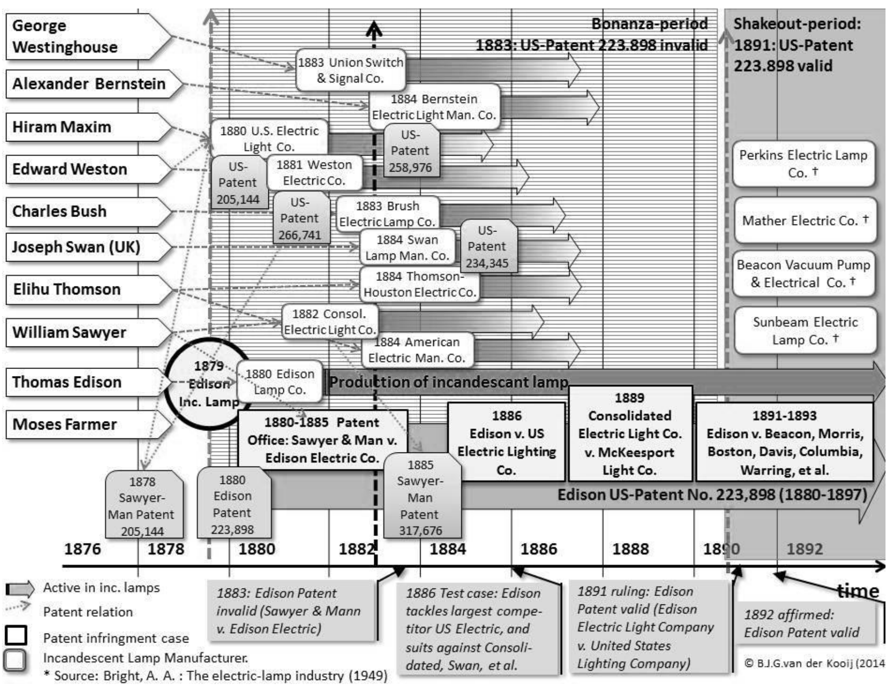

Figure 98: Patent litigation and patent wars around Edison's patent 223,898.

Inventors (left column) and their companies related to Edison's invention of 1879 and the resulting patent infringement and litigation. † indicates that activity was halted or company was not active anymore.

Source: Figure created by author

[95] After the creation of Edison General Electric in 1889, the managerial role of Thomas Edison in the management of his company was nil.

> *rights resulted in numerous law suits. It was after 1891–1892, that many infringement who were exploiting the limits of Edison's claims, were prosecuted: Edison Electric Light Co. et al. v. Sawyer-Man Electric Co., 53 F. 592, 599 [2nd.Cir.1892]; Edison Elec. Light Co. v. Beacon Vacuum Pump & Elec. Co., 54F. 678 (C.C.Mass. 1893); Edison Electric Light Co v. Mount Morris Electric Light Co, 57F. 642, 647 (C.C.N.Y. September 19, 1893); Edison Elec. Light Co. v. Boston Incandescent Lamp Co., 62 F. 397, 398 (C.C.Mass. 1894); Edison Elec. Light Co. v. Warring Electric. Co., 59 F.358 (D.Conn. 1894); Edison Elec. Light Co. v. Davis Electrical Works, 58 F.878 (D.Mass. 1893); Edison Elec. Light Co. v. Electric Manufacturing Co., 57 F. 616 (E.D.Wis. 1893). (Katznelson & Howells, 2012; Standler, 2011, pp. 6-7). All these lawsuits did not come cheap. Between 1885 and 1901 the Edison company and its successors spent about $2.000.000[96] on well over two hundred infringement suits under its lamp and lighting patents.* (Bright, 1949, p. 86)

Soon the playing field was under stress for a lot of companies manufacturing incandescent lamps.

> *For twelve years competition had been possible; it suddenly became impossible.*[97] *The Beacon Vacuum Pump & Electrical Company of Boston attempted to avoid an injunction early in 1893 by claiming priority of invention for Heinrich Gobel, a German-American watchmaker from New York, who was said to have built several carbon-filament lamps from 1854 to 1872 which anticipated Edison's later developments. Gobel had taken out no patents on his developments, however, and the evidence to prove his priority of invention was questionable. Judge Colt of the United States Circuit Court at Boston ruled that the evidence presented was not sufficient to invalidate Edison's patent, and he granted junction against the Beacon company on February 1893.* (Bright, 1949, p. 90)

The result was the closure of the lamp-manufacturing activities of many competitors (right side of Figure 98):

> *Within a short time injunctions had closed the lamp plants of the Sawyer-Man Electric Company, the Perkins Electric Lamp Company, the Mather Electric Company, and the Sunbeam Electric Lamp Company… Injunctions were shortly granted against several additional producers of incandescent lamps; and others closed down their plants without waiting for legal action against them.* (Bright, 1949, pp. 89-90)

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[96] This amount would be equivalent to more than $53 million in 2010, calculated on the basis historic standard of living. Source: Measuring Worth at http://www.measuringworth.com/uscompare/relativevalue.php.

[97] This is based on Bright's view. There are different other views of the blocking nature of Edison's patent, its "holding back" of the developments, and the resulting dominance of the market of incandescent lamps by General Electric (Katznelson & Howells, 2012, pp. 31-35).

But others stayed alive, working around Edison's patent position, like the Westinghouse Electric & Manufacturing Company. They produced another type of lamp after their infringing lamp had to be taken out of production. The patent protection for Edison's design, originally foreseen for January 1897, was cut short by another event. It was the expiration of the Canadian patent Edison was holding on an earlier date, November 17, 1894, than its American patent. This reduced the life of the basic patent by two years. Edison had not been the only one going to court in protecting his patent rights. Other manufacturers (also of arc lights) filed suits. It was a period dominated by patent conflicts.

> *Even though several patents for which broad claims were made were invalidated or limited in their coverage, others were upheld or clarified and gave greater strength to the largest firms in the industry—the Edison and Thomson-Houston companies and their successor, the General Electric Company, and Westinghouse. The costs of litigation sapped the strength of the smaller companies, even where they were successful in defending themselves. Many small independents were forced to liquidate or sell out.* (Bright, 1949, p. 87)

The application of incandescent light

It was obvious that the appearance of the incandescent light was fulfilling a need. The light was pleasant to the eye, could be used individually, and for the installation the old gas pipes in the house could be used (with adapters known as the "Edison base," like US-Patent №. 248,420, October 8, 1881) (Figure 99). They not only smelled less than a gaslight, but they were also much safer and could be used in fire-sensitive environments (like a library). That took care of the lamp and the in-house wiring, but there was also the power supply to that house. Therefore, a distribution system was needed: the DC-power system.

The electric direct current power system

One has to realize that Edison (and all those other inventors) not only developed the incandescent lamp, but often the whole concept of an "electrical system" (including the generation of electricity and the distribution of electricity), as well as important parts for the system, such as the holder for the lamp (Figure 99).

Edison had an example. He more or less copied the system the gas companies used: central gas generation, piped distribution networks, gas meters, and gas lamps in factories and residences (see his description for US-Patent №. 369,280 in Table 18). In doing this he was a direct competitor of the old gas companies, who were not inclined to be too

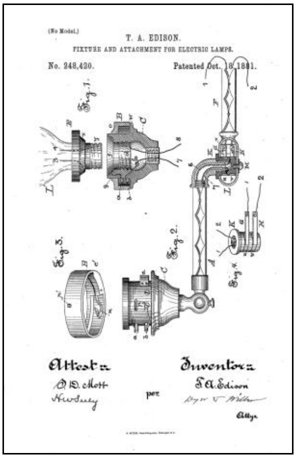

Figure 99: US-Patent №. 248,420 for the "Edison base."

Source: USPTO.

happy about this formidable competition.

With the opening of the Pearl Street station in lower Manhattan on 4 September 1882, Thomas Edison publicly presented a complete system of commercial electric lighting and power. The success of the Edison bulb created a demand for a source of power. It was this demand that led to the construction of the Pearl Street station and launched the modern electric utility industry. The Pearl Street station featured reliable central power generation, safe and efficient distribution, and a successful end use (that is, his long-lasting incandescent light bulb) at a price that competed with gas lighting. (IEEE, 2013)

Early DC system

The electricity was to be generated centrally with the help of the "prime mover," for example, a steam machine. This steam machine would be connected to the generator. These were the "central power stations" from where the electricity was to be distributed among its points of consumption.

> *In these central power stations, Edison realized the concept that had dominated all his work with the light, and his essential achievement was this combination of electrical devices in a comprehensive system for the production and distribution of electricity. The realization of this bold concept involved an immense amount of inventive and critical effort, as every phase of the work created entirely new problems. The dynamos embodied many novel features; the technique of wiring had to be developed; meters were required; fixtures were to be designed; last, but by no means least, the steam engine required improvements to increase the regularity of its operation.* (Usher, 1929, p. 368)

The development of the incandescent light was directly related to the development of the "central station" concept. The arc-lighting systems were then wired in series so all the lamps had to be operated continuously, as the failure or shutting off of any one lamp broke the whole circuit. The dynamos had to supply electricity generated with a *constant current*, and the lamps were switched on all together, like in a street-lighting system, a factory, or a theatre (Figure 100).

Edison adapted the idea from gas-lighting, where every burner could be individually turned on or off. This feature was to be included in electrical systems. It required high resistance for each individual lamp to be placed in a parallel circuit (Figure 101). Edison conceived the parallel circuit and worked out all the primary details of the wiring: the mains, the house circuits, and the connections with the dynamos (Usher, 1929, p. 366). Dynamos had to deliver electricity with a *constant voltage.*

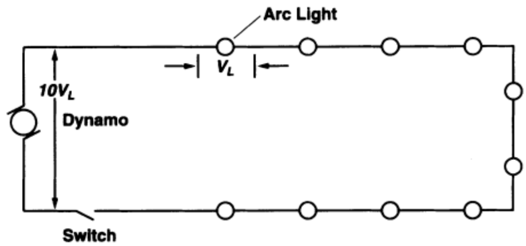

Figure 100: Series circuit for arc-lighting system.

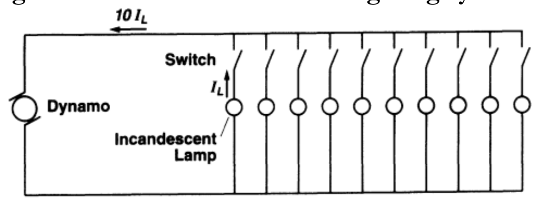

Figure 101: Parallel circuit for incandescent-lighting system.

Source: Passer, H. C: *The Electrical Manufacturers 1875–1900*, p. 81.

DC systems: Patents

The basic DC system consisted of three parts: the dynamo generating the DC electricity, the cabling with copper wires distributing it, and the lamps (the "load") consuming it. This was the case for both arc lights and incandescent lights. It had started with a one-to-one system: one source and one "load." But soon it was one dynamo with multiple "loads."

For the efforts to create distribution systems, a range of patents were granted (Table 18), both for ideas on the generating and consumption side, as well as the distribution by copper cables itself, like US-Patent №. 274,290, which was granted on March 20, 1883, to Thomas Edison for a three-wire system that resulted in smaller conductors, thus saving material and costs. It was followed later by other patents (like US-Patent №. 304,085, granted on August 26, 1883) expanding the idea. And he had to develop the components of the system, like the kWh-meter to measure the consumption of electricity. For this design he was granted US-Patent №. 242,901 on June 14, 1881 (later improved in US-Patent №. 370,123, granted on September 20, 1887).

Edison was not the only one working to solve the problem of the "division of currents" by designing the total system. William Sawyer was granted US-Patent №. 194,111 as early as August 14, 1877, for *"Electric engineering and lighting apparatus and system."* Charles Brush, the arc-light manufacturer, was granted US-Patent №. 267,077 on July 11, 1882, for a "system for transmitting electric currents to translating devices, consisting essentially in an electrical conductor divided along its length into two or more series of paths or branches, each path or branch of each series being electrically connected at opposite ends with the main conductor and translating devices interposed in said branch circuits."

Table 18: Patents granted for DC systems of electrical distribution to Thomas Edison

Patent №	Granted	Description
US 239,147	March 22, 1881	System of electric lighting: A system of laying the conductors conveying the current from a central station or source of electric energy throughout a system of electric lighting or translation
US 242,901	June 14, 1881	Electric meter: A meter indicating the amount of electricity supplied to the customer
US 248,422	October 18, 1881	System of electric lighting: Method for regulating the generative capacity of generators for multi-arc systems for instance, on ships where the system may be divided into subsystems, one for the cabin, one for the deck, and so on, as may be desired, or in cities, where the streetlamps may be arranged in special circuits or subsystems
US 251,552	December 27, 1881	Electrical distribution system: Underground conductor completely isolated and protected from moisture and other causes
US 264,642	September 19, 1882	Electric distribution and translation system: Preventing drop in tension in those portions of the system more remote from the central station
US 266,793	October 31, 1882	Electric distribution system: System of conductors supplying the district with electricity proportional to the demand
US 273,828	March 13, 1883	System of underground conductors for electrical distribution: More convenient manner of arranging and connecting the conductors at the intersection of two streets
US 274,290	March 20, 1883	System of electrical distribution: High-tension circuit diminishing the size of the conductors and where each lamp can be lighted and extinguished separately and without affecting any others
US 304,085	August 26, 1884	System of electrical distribution: An arrangement of the conductors and translating devices so that all the translating devices will be equidistant from the source of electrical energy
US 369,280	August 30, 1887	System of electrical distribution: In other words, to so contrive means and methods that electricity may be supplied for consumption in a manner analogous to the systems for the supply of gas and water without requiring any greater care or technical knowledge on the part of the consumer than does the use of gas or water, in order that economy, reliability, and safety may be ensured
US 369,443	September 6, 1887	System of electric distribution: One source supplying two or more distributing systems
US 370,123	September 20, 1887	Electric meter: Improved meter calculating consumption of electricity by mono-electrodynamic motor
US 404,902	June 11, 1889	Electrical distribution system: Underground piping of conductors

Source: USPTO.

DC distribution networks

As mentioned before, the gaslight was the first development that included, in addition to the product of the gas lamp itself, a distribution network for the supply of gas to the end user. After the generation of gas by distillation of coal, the gas was transported through pipes to the point where the gas was consumed: houses and factories (Figure 102). This was realized by the "gas utility industry," a range of gas companies generating and distributing gas. And there was the equipment industry: all those companies manufacturing products like the gas lamps themselves.

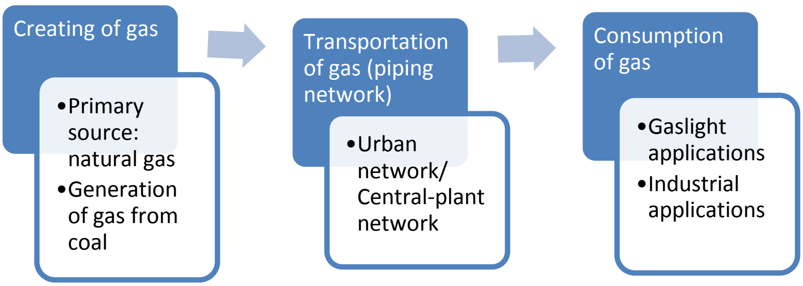

Figure 102: Overview of the system of generating, distributing, and consumption of gas.

> *The early history of those [utility] companies was marked by many failures, caused in part by financial and technical difficulties and also in part by widespread public opposition to the "health-menacing" new type of illumination. Gas lighting was also opposed by the dealers in oil and tallow lamps and candles, who feared its competition. Once in use, gas lighting underwent rapid changes in technique which enabled it to secure widespread acceptance and broaden out from street and industrial illumination to residential use.* (Bright, 1949, p. 20)

The same goes for electricity. Next to the manufacturing of products (the "equipment"), it was the total *system* of electricity generation and its distribution that became an important factor in the acceptance of electricity in everyday life. In the case of electricity, between the point where electricity is generated and the point(s) where the electricity is used, cables transport the electricity, first through a small network, then a local network, and finally large networks. Like the preceding developments in gas lighting, it was the comparable development of the "electric industry" that was not without problems of its own.

In the early days of arc light and incandescent light, the feasibility of electric light was shown at exhibitions. The public was fascinated. The exhibitions attracted large crowds. But before electric light became a common part of life, some decenniums passed by. The development of the electricity-distribution infrastructure took place within the context of conflicting interests, like the conflict with the gas industry: the owners of the old gas infrastructure and their financial interests. Here it was the "old technology" versus the "new technology." But there was more: the conflicting (business) interests within the applicants of the new technology, conflicts that influenced its development, like the conflict between those financially engaged (entrepreneurs, banks, private investors) who favoured local, privately owned systems (the profitable "isolated plants"), against those who promoted a centralized approach of the "central station" electric systems.

The wars with gas companies and public acceptance[98]

As explained, the new emerging electric-light systems, especially the incandescent-lamp systems, were a direct replacement for the existing systems of gas lamps, gas distribution, and gas production. In other words, electric light had to compete with the well-established "gas industry," just as the gas lamps had to compete with the oil lamps in the early nineteenth century.

> *The existing gas industry was not only well established, gas was inextricably woven into the city's physical and institutional environments. New York first lit its streets using gas lamps in 1825; by 1878, gas companies in the U.S. had a capital investment of approximately 1.5 billion dollars. In New York, these companies had integrated themselves deeply within the city's social, economic, political, and physical infrastructure, from their many gas mains buried under the streets to their extensive corps of city-employed lamplighters, to their powerful influence over the aldermen and mayor of New York—the political machine of Tammany Hall.* (Hargadon & Douglas, 2001, p. 484)

So Edison not only had to fight the gas companies themselves, but also the institutions and individuals that had a vested interest in its existence—as well as those that were in direct competition with it: the arc-light industry.

> *William Vanderbilt, for example, was one of Edison's largest investors and also the largest owner of natural-gas stock in America, having bought Edison Electric Light Company stock as a hedge against this new technology…Newly established arc-light inventors and manufacturers also publicly warned that Edison's plans were "so manifestly absurd as to indicate a positive want of knowledge of the electrical circuit and the principle governing the construction and operation of electric machines."* (Hargadon & Douglas, 2001, pp. 485-486)

98 Recommended background reading: Thomas Gillen: *From darkness to light: The plot to sabotage the invention of the electric light* (Gillen, 2003).

Gas manufacturers responded to the challenge with two major advances. The first was better-quality gas. The second was an incandescent mantle invented by Carl Auer von Welsbach of Austria (who later worked on the metal-filament lightbulb). Both innovations resulted in brighter, more efficient light.

The inventions might be realized, the products developed, and the distribution infrastructure slowly growing, but the acceptance by the general public was slow. In those areas where electricity was distributed, where certain standardization was realized, still some aspects hindered the acceptance by the general public. One reason certainly was the economic aspect of cost, but the other, psychological aspect also had quite an effect. Electricity was not something an ordinary person could sense, feel, smell, or see—except when touching the live wires, of course. And that was quite frightening, all the more when accidents happened and the journals reported with headlines like "Electric wire slaughter," "Electric murders," and "Another corpse in the wires." When bad weather added to the problems, the danger of electricity was even larger (Figure 103).

Figure 103: Street scene in New York (1881).

Source: *Harper's Weekly*, April 9, 1881.

> *When ice storms felled telegraph poles and wires throughout the city, mounted firemen roamed the streets warning pedestrians about the danger of live wires. As observable as the benefits of electric lighting may have been in the early 1880s, its dangers, which included occasionally electrified streets and electrocuted workers, were still more visible.* (Hargadon & Douglas, 2001, p. 487)

From isolated plant to centralized networks

From the conception of the electric incandescent lamp and the electric arc lamp to the broad implementation of electric lightning in houses and workplaces, it took a while. In the beginning it was on an "isolated" scale dominated by private installations. Soon these small "isolated" networks expanded (Figure 104) into "urban networks" serving a greater group of users (blocks, municipal), and finally into the "central plants," from where electricity was a commodity to be sold to large groups of end users.

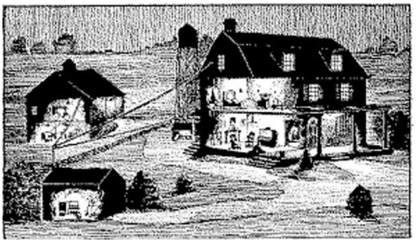

Figure 104: View of a typical isolated plant on a farm: barn, tool, & pump house and house itself.

Source: *Hawkins Electrical Guide Number Seven* (1915), p. 1549.

Edison strongly argued that electricity should be the primary commodity and that electricity should be sold by separated companies taking a license on his (patented) system. His companies then in their turn would manufacture equipment to be sold to those central stations. This business concept was different from that of those adhering to the "isolated plant" concept. Here equipment would be sold to each building owner, who would generate his own electricity. This was done by entrepreneurs who propagated the profitable "on-site electric" lighting systems with their "isolated plants."

> *Isolated systems (in individual homes and factories) were viable and would be the most common supplier of electricity to consumers through 1915 in most cities. While economic arguments were mounted on behalf of each type of service, it appears that isolated systems in a factory or apartment building were at least as viable as other decentralized amenities, including home furnaces, water wells, and personal automobiles. Isolated systems had significant first mover advantages: thousands had been sold before Edison ever opened his first central station.* (Granovetter & McGuire, 1998, p. 4)

In addition to the "isolated plants," other distribution networks developed, like the so-called "urban networks":

> *There were also neighborhood systems serving small geographic territories. Some were dedicated co-generation systems supplying a neighborhood with both electricity and steam for heat. Other neighborhood systems originated in a "base" factory, hotel, or trolley firm, and then sold "surplus" current to other nearby customers…Yet by 1915 most of these decentralized and multi-purpose firms were subsumed, or undermined by technical licenses and patent monopolies and these alternative constructs for the boundaries of the electric current industries had begun to wither. A cross-licensing agreement between General Electric and Westinghouse, for example, severely limited competition in electrical equipment, leading to their 1911 prosecution for anti-trust violations. Moreover, regulatory bodies weighed in against these decentralized alternatives with prejudicial rulings."* (Granovetter & McGuire, 1998, pp. 10-11)

Figure 105: Westinghouse advertisement for isolated, block, municipal, and central stations.

Source: Covington, http://home.frognet.net/~ejcov/kocsis7.jpg.

Originally there were "isolated plants" manufactured and sold by a range of companies. But soon some entrepreneurs started selling electricity to those who wanted light: the "municipal networks." It was the beginning of a path to the "centralized plant-system" concept, a concept that was completely different from the "isolated plants." (Figure 105)

> *Individuals, merchants, hotels, and theatres had purchased plants and arc lamps; they had had their premises wired; and the lights, supplied from their own private generating plants, were utilized for private benefit on their own property. These were designated as "isolated lighting plants."…The San Francisco Company was the first in this country, if not in the world, to enter the business of producing and selling electric service to the public…Customers were not lacking, though the rate was high. A flat rate of $10 per week per lamp*[99] *was charged, as metering of the current was quite unknown. As the system was improved, rates were reduced, until eight years later it was $3.00 per week for current furnished up to 9:30 o'clock in the evening (11:00 on Saturdays), $4.00 for current up to midnight, and $6.00 for all-night service. No current was furnished on Sundays and holidays.* (Hammond, 1941, p. 28)

It was Edison who played an important role in the development of the centralized plant system:

> *Alongside these "isolated plants"…a fledgling industry of privately-owned central electric stations blossomed from less than two dozen firms in 1882 to almost five hundred in 1885 and almost two thousand independent local firms by 1891, using different technologies and organizational structures. These firms were*

[99] This amount would be equivalent to more than $250 in 2010, calculated on the basis historic standard of living. Source: Measuring Worth at http://www.measuringworth.com/uscompare/relativevalue.php.

> *hobbled by local governments and large equipment manufacturers, and wracked by destructive competition…*
>
> *Central station electric systems were a major commitment for Thomas Edison, who mobilized his personal financial and patent-based resources and those of his subordinate co-workers and their families to create and manage the Edison (later General Electric) electrical equipment manufacturing firms…*
>
> *Edison also mobilized long-standing associates to sell and/or invest in several central station firms. They secured funding for several additional central station firms by exploiting antagonisms and fears among financiers…And by exchanging equipment for securities of local firms, Edison created shared ownership between the patent-owners, equipment manufacturing firms, and central station firms…* (Granovetter & McGuire, 1998, pp. 150-151)

The first central stations were oriented almost entirely to lighting, and Edison, like most others, underestimated the subsequent demand for current used to power motors. The capacity of central stations in the 1880s was rated by the number of lamps they could support. (ibidem p.168)

This all was part of the development of an electricity-distribution infrastructure that went from *isolated systems* to *centralized systems*, a process with quite some dramatic aspects, from patent-based monopolies to fierce business competition between a multitude of companies. Among those many companies was the Mather Electric Company.

Mather Electric Company

Together with the arc light, the incandescent lamp was part of a total system that was supplied by a range of different manufacturers. A system for *Direct Current Incandescent Lighting* was offered by the Mather Electric Company, of Manchester, Connecticut (Figure 106). In their promotion booklet (Mather, 1884) they stated:

> *The Mather System of Incandescent Lighting and Transmission of Power is owned and controlled absolutely by The Mather Electric Company, and the business of manufacturing and installing the Mather apparatus will in the future as in the past be conducted without reference to, or association with, any other company.*

The Mather "system of incandescent lighting" they offered to the public consisted of a generator, incandescent and arc lights, switchboards, ampere- and voltmeters, and switches. In other words, they offered complete installations for hotels, restaurants, theatres, ships, factories, and so on.

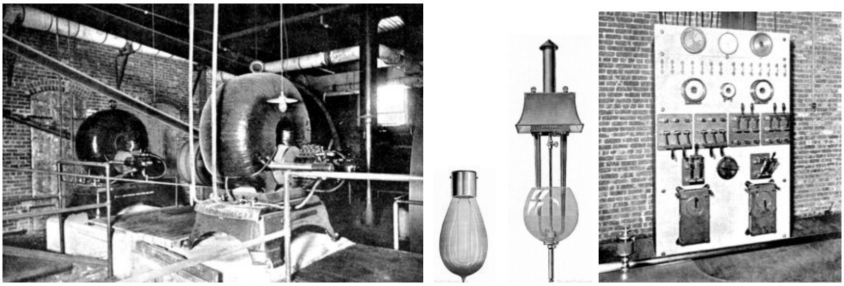

Figure 106: The components of Mather's system of incandescent lighting (1884).

From left to right: generator with power belt, incandescent lamp, arc lamp, switchboard. Source: (Mather, 1884).

The generator was being promoted as efficient and reliable: "The Mather dynamo is constructed upon thoroughly scientific principles and is theoretically perfect in electrical design. The electrical efficiency of the dynamo, therefore, is extremely high—higher than even claimed for other machines." And they offered a range of generators: "The Mather dynamos are manufactured in capacities varying from 50 to 3,000 lights of 16 candle-power each. They are regularly constructed with compound winding for a constant potential of 125 volts, but can be furnished of any desired potential to order at short notice."

The incandescent lamp was promoted as having a long life and efficiency: "The efficiency of the PERKINS Lamp is so high that when combined with the Mather dynamo it produces more actual candle-power per horse-power throughout its average life than any other incandescent lamp yet produced." It was offered in combination with an arc light: "we have perfected the system of arc lighting from the incandescent current, which renders possible for the first time a perfect electric lighting system, the arc and incandescent lamps on one circuit, operated by the same dynamo, measured when desirable through one meter, and both governed by the same rules of safety."

The switchboard was offered for isolated plants and central plants: "The ampere-meters, for measuring the quantity of current, and the volt-meters, for measuring the electromotive force or pressure, are made on the steam-gauge pattern, mounted in polished brass cases in the most substantial manner. The various switches for handling the current are also made of polished brass and have ample contact surfaces and carrying capacity; they are mounted upon slate or marble bases, and are therefore incombustible."

And the pamphlet concluded:

> *It has always been our object to give our customers the best apparatus that science, money, and skilled labor can produce. In return we ask only a fair manufacturer's profit.*

Pearl Street: the central-station concept and limitations of DC[100]

Figure 107: The First District (below) in Manhattan, New York City.

Shown is the underground DC mains that Edison wanted in this densely populated area of Southern Manhattan known as the First District.

Source: Annual report Edison Electric Illuminating Company of New York, 1893. http://www.columbia.edu/cu/lweb/digital/collections/cul/texts/ldpd_6281133_000/ldpd_6281133_000.pdf ; www.pbs.com.

Edison decided to promote his incandescent lamp and his concept for the "central station." He created the *Edison Electric Illuminating Company of New York*, a spin-off from the *Edison Electric Light Company*, the license holder, and decided to build a demonstration station that came to be known as the *Pearl Street Central Generation Station* in New York in 1882 (Figure 108). In the high-profile area of Manhattan, New York, the First District was a densely populated area, with both commercial and residential customers (Figure 107).

The first day of operation, September 4, 1882, it lighted the premises of eighty-five customers, among which were the lamps at 23 Wall Street, the offices of Drexel, Morgan and Company, as well as the lamp at the offices of the *New York Times* at 255–257 Pearl Street. In total the first day four hundred lamps burned. Within a year that grew to 8,573 lamps burning at 513 customers. In addition to being a densely occupied area, the decision for the financial district had other reasons as well. This was the center of big finance; here were located the investors, the stockbrokers, and the banks that mattered, as well as the head office of the *New York Times*. However, the paper only mentioned the opening of the station somewhere inside the next day's paper.

100 Text based on numerous sources, among them http://www.ieeeghn.org/wiki/index.php/Pearl_Street_Station; www.jhalpin.com/metuchen/tae/ehlai17.htm.

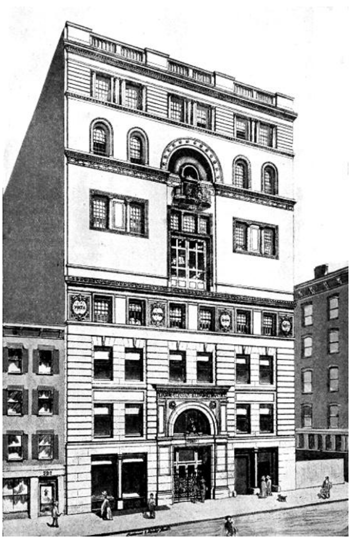

Figure 108: Pearl Street Station at Pearl Street.

Source: Annual report Edison Electric Illuminating Company of New York, 1893. http://www.columbia.edu/cu/lweb/digital/collections/cul/texts/ldpd_6281133_000/ldpd_6281133_000.pdf ; www.pbs.com.

Technically the Pearl Street Station was quite impressive. It contained on the ground floor the big Porter-Allen steam machines, with their big Babcock & Wilcox steam boilers that could consume five tons of coal and 11,500 gallons of waters per day. On the upper floor were located the large, heavy (27 ton, 100 Kw) electric jumbo-generators, generators that supplied (at full throttle) 850 amperes of DC current at 115–120 volts. They were designed to light twelve hundred sixteen-candlepower lamps.[101] To support all that weight, special construction had been needed. And being in a narrow street and a congested district, the plant needed special facilities for the handling of coal and ashes, as well as for ventilation and forced draught.

Figure 109: Underground cabling.

Source: www.schenectadymuseum.org/edison/a_timeline/images_02/d02_04.htm.

One of the major problems was to install the electrical cabling underground in the streets (Figure 109). Edison had to obtain a permit for laying his cables underground.

> *Edison's decision, for reasons of safety, to lay underground mains, however, necessitated a franchise that could be obtained only by a company organized under the gas statutes. [He needed] a franchise which had to be granted by the New York City Board of Aldermen. The powerful gas lights interests in New York were apparently behind the*

[101] The old-fashioned unit of light, one candlepower was the light produced by a pure spermaceti candle weighing one sixth of a pound and burning at a rate of 120 grains per hour. A 100–watt common incandescent bulb emits about 120 candlepower.

opposition of several aldermen to the Edison concerns. In late December 1880, Lowrey[102] *brought the key officials from the city government via a special train to Menlo Park to examine Edison's system. After demonstration and a tour, the weary officials were taken to the second floor of the laboratory building. One of Edison's associates later recalled that the lights went suddenly on, "revealing a spread such as only old New Yorkers could describe," catered by the famous Delmonico.*[103] *The franchise was granted in April 1881.* (Derganc, 1979, p. 58)

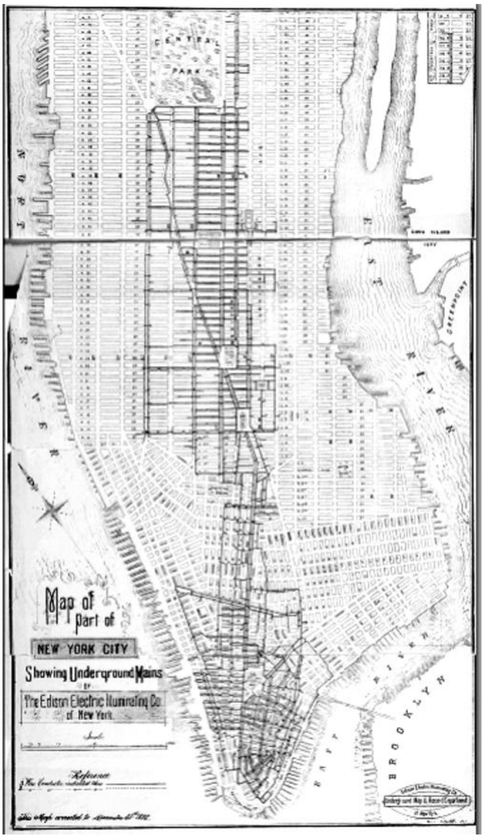

Figure 110: Expansion of the underground cabling system (1893).

Source: Annual report Edison Electric Illuminating Company of New York, 1893. www.columbia.edu/cu/lweb/digital/collections/cul/texts/ldpd_6281133_000/ldpd_6281133_000.pdf.

The lobbying, both the demonstrations and the dinner, seemed to have been successful as it resulted, quite a while later, in an extended underground network of electric cabling in 1893 (Figure 110). This illustrates the way one obtained a government contract in the 1880s: through payoffs, bribes, and kickbacks (Brandon, 2009, p. 69). The fifteen miles of tube conductors and connecting and junction boxes were made by the *Edison Tube Works*. The installation of the pipes in the streets was quite a task. As Edison recalls:

When we put down the tubes in the lower part of New York, in the streets, we kept a big stock of them in the cellar of the station at Pearl Street. As I was on all the time, I would take a nap of an hour or so in the daytime—any time—and I used to sleep on those tubes in the cellar. I had two Germans who were testing

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102 Grosvenor P. Lowrey, a lawyer who became legal financial adviser to Edison, had close contacts with the New York financial and political world. He arranged this lobby extravaganza with the purpose of obtaining a franchise (Hughes, 1979, p. 131).

103 Delmonico's was a famous restaurant in the First District of New York that catered to the rich.

there, and both of them died of diphtheria, caught in the cellar, which was cold and damp. It never affected me. (Martin, 1929, p. 399)

Countless other problems plagued the station during the breaking-in period (Hughes, 1993, pp. 41-43), not all of them being of a technical nature, though, as illustrated by the following Edison remembrance:

When I was laying tubes in the streets of New York, the office received notice from the Commissioner of Public Works to appear at his office at a certain hour. I went up there with a gentleman to see the Commissioner, H. O. Thompson. On arrival he said to me: "You are putting down these tubes. The Department of Public Works requires that you should have five inspectors to look after this work, and that their salary shall be $5 per day, payable at the end of each week. Good-morning." I went out very much crestfallen, thinking I would be delayed and harassed in the work which I was anxious to finish, and was doing night and day. We watched patiently for those inspectors to appear. The only appearance they made was to draw their pay Saturday afternoon.
(Martin, 1929, p. 392)

In the year 1882, the customers were not charged, so there was no income. That changed in 1883, when on the investment of $828,800, a net income of 6 percent was reported. After 1884 the project proved that the central-station concept was economically feasible, as the "earning/revenue" ratio always showed nice figures (Table 19).

Table 19: Edison Electrical Illuminating Co. of New York: Data for the Pearl Station plant and the company

	1882	**1883**	**1884***	**1886***	**1888***	**1890***	**1891***
Users/cust.	85	513	-	-	710	1,698	2,875
no. of lamps	400	8,573	-	-	16,377	64,174	94,485
Arc lamps	-	-	-	-	125	254	841
Total motor HP	-	-	-	-	470	697	2,000
Revenues	-	-	$111,872	$157,579	$226,301	$446,268	$635,575
Net earnings (after tax)	-	-	$33,222	$70,051	$116,235	$229,078	$347,228
Earning/ revenue ratio	-	-	29.7%	44.6%	51.3%	51.3%	54.6%
Net earnings (equivalent)**	-	-	**$0.7 M**	**$1.55 M**	**$2.57 M**	**$5.25 M**	**$7.8 M**

* Figures for the New York Utility: Edison Electric Illuminating Co. of New York, Annual Reports 1890–1892.

** 2010 equivalent (based on historic opportunity cost calculation: www.measuringworth.com).

Source: http://www.columbia.edu/cu/lweb/digital/collections/cul/texts/ldpd_6281133_000/ldpd_6281133_000.pdf.

Soon after the First District was served, the expansion into other districts of Manhattan was started. In the 1891 Annual Report[104], it reads:

> *The outlook at the beginning of last year led your Directors to recommend large additional installations, covering territory not theretofore occupied, also important additions to the existing plant. A plan to accomplish these purposes was adopted at your last meeting, and it is now being carried into effect. This plan provided for the increase of the capital stock from $2,500,000 to $4,500,000, and the creation of a mortgage to secure $5,000,000, 5% convertible bonds, of which $2,000,000 were to be issued. All of these securities were duly subscribed for, the bulk of them being taken by the stockholders of the Company under the option offered them, which provided for payments in installments as called for by the Company.*

The life span of the station was not too long, though: The Pearl Street Station was destroyed on January 2nd, 1890 by fire and a reconstructed station became operational on January 12th of that year. On April 1st, 1894

Table 20: Financial data for the Edison Electrical Illuminating Co. of New York (1892–1898)

	1892*	**1893***	**1894***	**1895***	**1896***	**1897***	**1898***
Users/ custmrs	4,334	5,154	5,877	6,675	7,898	8,711	9,990
Inc. lamps	142,492	192,691	234,494	271,123	309,369	382,291	443,074
Arc lamps	1,637	2,538	3,014	3.424	5,559	7,201	7,353
Total motor HP	3,807	5,529	7,616	12.046	15,953	19,380	24,438
Revenues	$963,021	$1,245,524	$1,646.336	$1.675.231	$1,771,229	$2,466,255	$2,898,021
Net earnings (after tax)	$475,137	$605,642	$789,466	$915.758	$960,156	$1,117,497	$1,277,129
Earning/ Revenues ratio	49.3%	48.5%	47.9%	54.6%	54.2%	45.2%	44%
Net earnings (equivalent)**	**$10.7M**	**$13.6M**	**$18.4M**	**$21.6M**	**$22.4M**	**$26.1M**	**$29.5M**

* Figures for the New York Utility: Edison Electric Illuminating Co. of New York, Annual Reports 1890–1899.

** 2010 equivalent (based on historic opportunity cost calculation: www.measuringworth.com).

Source: http://www.columbia.edu/cu/lweb/digital/collections/cul/texts/ldpd_6281133_000/ldpd_6281133_000.pdf.

[104] Source: Edison Electric Illuminating Co. of New York. Annual report of the Board of Directors to the stockholders at their annual meeting ... [New York] : The Edision Electric Illuminating Co. of New York. Electronic reproduction. 1890-1898. New York, N.Y. :Columbia University Libraries, 2008. http://www.columbia.edu/cu/lweb/digital/collections/cul/texts/ldpd_6281133_000/pages/ldpd_6281133_000_00000006.html

the station was retired. But the electrification continued. By 1909 the New York Edison Company (being the successor of the Edison Electric Illuminating Company of New York) was operating twenty-eight stations and substations. (Martin, 1929)

Edison had proved his point. The DC-lighting concept with the central-station concept was technically and economically feasible, as the financial results showed (Table 20). But the project was also a success in other aspects. Considering the conservative approach of those who were financing Edison's local plant installation, the concept of a central station was not received with great enthusiasm. But the Pearl Street demonstration changed that.

> *As a technical demonstration that Edison's system could function, the station proved a resounding success. Edison's financial backers, content with growing sales of stand-alone "isolated" generating plants, urged caution in promoting central station power—they wanted to see Pearl Street in operation first. Satisfied with the station's performance, they began licensing central systems throughout the U.S. By the end of the 1880s, dozens of Edison companies were in business.*[105]

By 1888 large Edison companies or utilities were located in Detroit, New Orleans, St. Paul, Chicago, Philadelphia, and Brooklyn, New York. The New York utility reported dramatic growth (Table 19, Table 20) and reported also its first "motor load," an electric motor of 470 HP, connected to its network. It was a sign of the changing *era of light* into the *era of power*.

By the end of the 1890s, the *Edison Electric Illuminating Company of New York* had expanded considerably in terms of users/customers, installed base of incandescent lamps, arc lamps, and "motor loads." And it was quite a profitable operation, with an earning revenue ratio hovering around 50 percent for nearly a decade (Table 20). To supply electricity to all these users, it also had added a range of additional central-station generating plants: at 47–49–51 West Twenty-Sixth Street,

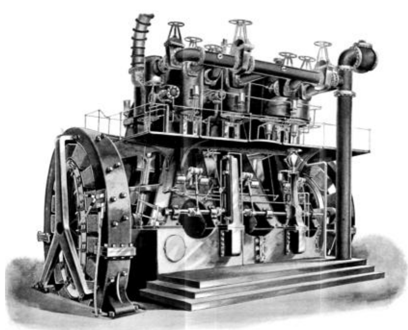

Figure 111: Edison 1250 HP central station at Elm Street, New York (1891).

Source: Annual report Edison Electric Illuminating Company of New York, 1893. www.columbia.edu/cu/lweb/digital/collections/cul/texts/ldpd_6281133_000/ldpd_6281133_000.pdf.

[105] Text source: http://americanhistory.si.edu/lighting/19thcent/promo19.htm.

117–119 West Thirty-Ninth Street, 118–20–122 West Fifty-Third Street, and the Annex Station at 200 Elm Street (Figure 111). By 1886 the two-phase AC system was introduced, connecting the stations with one another.

Basic problem of DC

The total electrical system of Pearl Street Central Station consisted of a supply side (the generators), a distribution network (the copper cables), and the user side with the "loads" (i.e., lamps), as shown in Figure 112.

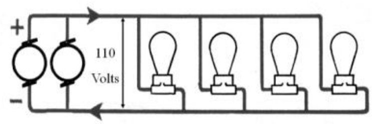

Figure 112: Principle of two-wire DC system.

Source: www.ieeeghn.org/wiki/ images/5/ 53/02-Edison_Central_Station_3 _wire_dc_system-16.GIF.

However, DC current-based systems have a basic problem. That is the drop of the voltage over the distribution wires (Figure 113).[106] Let's assume that the resistance of the load (in this case, the low-resistance lamps) is, for example, 100 ohm. Assuming that resistance of the copper wire bringing the electricity to the lamp is 0.015 ohm/m, then 1,000 meters of wire total up to 15 ohm (R_{line} in figure). That means that the original voltage from the generator, let's say 115 volts (V_{IN} in figure), results in 100 volts (V_L) in figure) available for the lamps (R_{Load} in figure), as 15 volts is the drop over the cable length. Increasing the length to 2,000 meters would increase the resistance to 30 ohm, resulting in a voltage drop of 30 volts, leaving 85 volts available for the lamps. This is the voltage drop over longer distances.

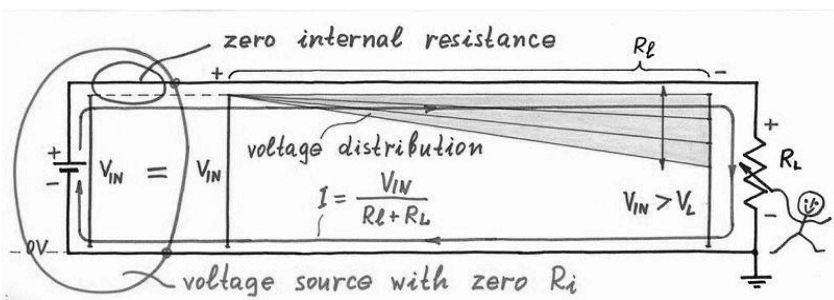

Figure 113: Principle of voltage drop over distribution wire by increasing load.

Source: Wikimedia Commons.

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106 For explanation of the technicalities of this subject, see Hawkins Electrical Guide Number Seven. Source: http://www.meekmark.com/dp/Hawkins7/ projectID421e9ab940c97.html.

The solution would be to use thicker copper wire, decreasing the resistance of the wire. But then the investment in copper cables increases considerably. According to Edison's own calculations for a generating plant the size of the Pearl Street station, the costs of the copper conducting lines alone came to over a third of the total capital investment needed for the entire plant. (Hughes, 1993, p. 39).

The voltage drop is not only related to distance; variations in the load (number of lamps) have the same effect. Assuming the same resistance of the wire (0.015 ohm/m) and the same length of 1,000 meters, the total resistance (R) again is 15 ohm. When the current (I) is 1 ampere, the voltage drop is, using the formula V = IR, 15 volts. When more lamps are used, the current increases to, for example, 2 A. The voltage drop becomes 30 volts. So, a generator of 115V leaves just 85 volts for the increased number of lamps.

The result would be that switching on another lamp, and thus increasing the current through the copper wire, would be noticed as the other lamps would be giving less light due to the voltage drop. In other words: someone in one room using the light would notice it when somebody else in another room switched on his or her light.

This basic technical property of DC systems resulted in a limited area for distribution of electricity. For this problem several technical solutions were available, one of them being at the user side of the network: the high-resistance incandescent lamp. Others could be found in the method of generating the electricity: the supply side, where the voltage of the generator could be increased. And some could be found at the transmission and distribution side: the cabled network.

To compensate for the voltage drop-problem, Edison introduced the three wire system; a distribution system where two or more generators placed in series were used (or generators of a special type). His idea was protected by his US patent

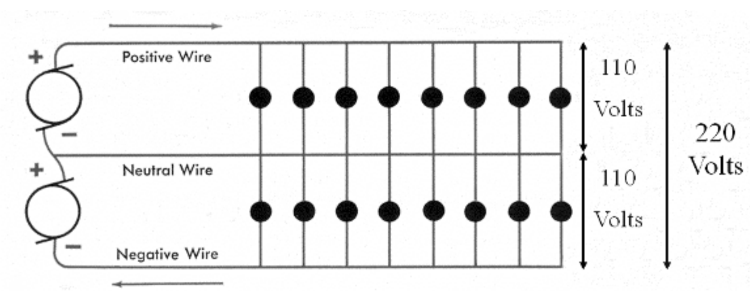

Figure 114: Principle of Edison's three-wire DC system.

Source: http://www.ieeeghn.org/wiki/images/5/53/02-Edison_Central_Station_3_wire_dc_system-17.GIF.

> *№. 274.290 granted on March 20th, 1883. The basic mechanism being that each generator having its voltage (let say 110V), the two in series coupled generators would have a potential difference of 220V. Distribution of the loads at the user side evenly over the two generators, this would permit the reduction of the size (diameter) of the copper wires, thus creating an economic advantage.* (Paul, 1884).

This three wire system (Figure 114) was pioneered by the *Edison Electrical Illuminated Company of Shamokin* in the small town of Sunbury, Pennsylvania, and it was started in operation on July 4, 1883 (Figure 115). The Sunbury generating plant consisted of an Armington & Sims engine driving two small Edison dynamos having a total capacity of about four hundred lamps of 16 c.p. (candlepower). The way this central station came to be illustrates the way Edison exploited his patents by creating the so-called "Edison companies."

In the late 1800s, Pennsylvania's booming anthracite-coal industry was not just fueling the nation; it was also fueling the growth of prosperous and forward-looking cities and towns throughout the coal-mining regions. It should not be surprising, then, that in 1882, about the same time that the Electric Illuminating Company of New York first lit up Manhattan nights, a group of investors in Shamokin, Pennsylvania, contacted Thomas Edison and expressed their confidence in his new carbon-filament lamp by offering to finance construction of a power station in their hometown. Early that fall Edison and his secretary arrived in Shamokin and met with the group of potential investors, who organized the Edison Electrical Illuminated Company of Shamokin, which received its state charter of incorporation that November. Edison then took up residence in town and supervised

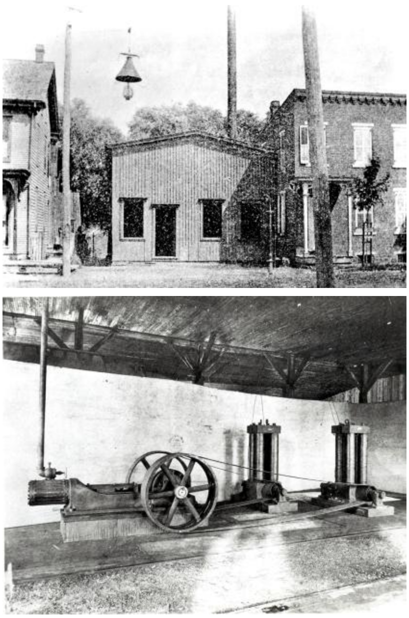

Figure 115: Sunbury, PA, central station using Edison's three-wire system (1883).

Exterior (top) and interior (bottom). Steam cylinder on the left.

Source: www.explorepahistory.com/displayimage.php?imgId=1-2-1B6F; http://engineeringhistory.tumblr.com//

the construction of a brick power plant on a swampy piece of ground abutting a spur of the Pennsylvania Railroad.

Shamokin, however, would not be the world's first town illuminated by a three-wire electric-light station with overhead conductors. Soon after his arrival in Shamokin, Edison also licensed an electric company with investors in Sunbury, some sixteen miles to the southeast. Using Sunbury's City Hotel as its base, the Sunbury Company built a coal-fired power plant on a vacant lot at the corner of Vine and Fourth streets in just three weeks. After a three-wire line was strung to the City Hotel, Edison, on the night of July 4, 1883, switched on the current to a 100-candlepower light over the City Hotel entrance to the cheers of residents and marches played by a local brass band.

> *On September 22, Edison was back in Shamokin, where a large crowd followed him to the home of Katherine McConnell, an enthusiastic supporter and investor in the company who had consented to have the kitchen of her mansion on East Independence Street wired. Fearful about the safety, however, "Aunt Kitty" had only permitted wiring of the kitchen and insisted that the wire run on the surface of the wall. The crowd then followed Edison a few blocks to the corner of Rock and Sunbury streets, where they watched the lights go on in Abe Strouse's store, in a building owned by Illumination Company president William Douty. They then walked to their third and final stop, Saint Edwards Catholic Church on Shamokin Street, which that night became the first church in the world to be lighted by electricity.*[107]

The invention of the incandescent lamp

That the invention of the incandescent lamp was a momentous event in the development of electricity is without question. Trying to answer who was or were the inventor(s) of the incandescent lamp is a more complex undertaking. This question has been a topic of discussion since Edison obtained his US-Patent №. 223,898 in 1880.

From a *legal point of view*, there is much that concerns the discussion of "priority." As his "098" patent was soon challenged in the US infringement case *Sawyer and Man v. Edison* in 1883, in the findings resulting from legal investigations, a first answer can be found:

> *I think it is clearly and fully shown that Sawyer and Man were the first inventors of the incandescent conductor for an electric lamp formed of carbonized paper. [Decision of E. M. Marble, Commissioner of Patents, in Interference between Sawyer & Man and Edison, 1883).* (Pope, 1894, p. 59)

107 Text source: http://explorepahistory.com/hmarker.php?markerId=1-A-399.

So one could be inclined to conclude that Sawyer was the inventor of a certain type of incandescent lamp: the vacuum, carbonized-filament type of incandescent lamp. But then there was the infringement case against *United States Electric Lighting Company* in 1885. Eventually on October 6, 1889, a judge ruled (in the United States Court of Appeals verdict in *Edison Electric Light Company v. United States Lighting Company*) that Edison's electric light-improvement claim for "a filament of carbon of high resistance" was valid. So one could be inclined to conclude that Edison was the inventor of a certain type of incandescent lamp: the high-resistance, vacuum, carbonized-filament type of incandescent lamp. It seemed more a question of what was to be considered the incandescent lamp—a question of definitions then.

From a *practical point of view*, looking at the technical performance and market acceptance of Edison's lamp, the juridical view is supported. The experiments of the aforementioned predecessors, like James Bowman Lindsay and associates, certainly were steps taken on the road of basic development (Henry Goebel's claims proved to be a hoax), but the massive development efforts Edison undertook in Menlo Park created a functioning and practical device:

> *Earlier workers had advanced to the same or higher degree in their work as did Woodward and Evans. To name a few: J. B. A. M. Jobard in 1838, C. de Changy in 1856, John Wellington Starr in 1845 and Joseph Swan in 1860. All these workers contributed, in one way or another, to the eventual development of the incandescent lamp, but it was Thomas Alva Edison who put the necessary ingredients together to make the lamp and system practical.*
> (Covington, 2013b)

One can also look at Edison's effort from a *technical point of view*. To the historian/economist Abott Usher, three elements were crucial to the successful invention of the incandescent lamp: (1) a high lamp resistance, (2) solving the problem of occluded gases, and (3) the use of carbon for the filament material (Usher, 1929, 1955, 2011).

> *Edison's work with the incandescent lamp is somewhat of a border-line case between discovery and invention. Strictly speaking, the discovery of the properties of a carbon filament was a necessary condition of the invention of the lamp. The critical achievement was thus a discovery rather than an invention.*
> (Usher, 1929, p. 18)

Regarding the first point, Usher stated:

> *Edison's attention was turned for the moment to the general design of a lighting circuit. It was, in fact, as much of a problem as the light itself, for all arc-lighting systems were then wired in series so that all the lamps must needs be operated continuously, as the failure or shutting off of any one lamp broke the whole circuit.*

> *Edison conceived the parallel circuit and worked out all the primary details of the wiring; the mains, the house circuits, and the connections with the dynamos. This work, which was highly original throughout, redefined the problem of the lamp; for no adequate illumination could be secured unless the resistance of the lamp were increased far above any limits previously tried.* (Usher, 1929, pp. 366-367)

As for the second point, Usher stated:

> *Before sealing the globe, however, Edison took one more new step. He had concluded from previous experiments that gasses were occluded in the carbon itself, which would blacken the globe and reduce the efficiency of the lamp if allowed to remain.* (Usher, 1929, p. 368)

He addressed the third point by stating:

> *An experiment was finally tried with laboriously prepared apparatus and results were achieved which led to protracted experiment with various kinds of carbon filaments. These carbon products combined all the essential properties: resistance, infusibility and indestructibility. After prolonged experimentation with different kinds of vegetable fiber, filaments were turned out which ran to over 1,500 hours of life.* (Usher, 1929, p. 18)

From the *point of view of the impact* of Edison's invention, one can just look at the dominance of Edison's companies in the market for incandescent lamps:

> *Nevertheless, according to the Edison Company, all its competitors combined had placed only 84,600 incandescent lamps in isolated plants and central stations by October 1, 1886. This was only about one-fourth the Edison total of over 330,000 lamps installed by the same time.* (Bright, 1949, p. 75)

Edison's development efforts were based on his vision of the total electric-lighting system he was creating. Combined with his business sense of how to bring the new technology to the market, this resulted in the working, payable, and usable product "electric incandescent lamp." Others were certainly on the same technological track but lacked the business feeling. Some might even have been more of a technical genius than Edison, but missed his vision on the system. Some more shrewd businessman might have been more commercial, but lacked the technical understanding to see in what direction the developments were going and missed the boat completely. It was the synergy of technology, market, and business development that made the Edison incandescent lamp such a basic innovation.

> *A close look at the evidence, and particularly at the chronology of events during that period [autumn 1879] gives little reason to believe to consider an outside*

> *origin for the carbon filament idea…concluded that it was Edisons work that laid the foundation for the electrical light and power systems to come.* (Friedel & Israel, 2010, p. 191)

That being said, certainly Edison's incandescent lamp, due to its technical concept and its impact in society, deserves a mark as being an important innovation.

A cluster of innovations for the incandescent lamp

We have seen that the developments preceding the Edison incandescent lamp (Figure 117) were hampered by the power supply that was available. Although the "wet cell," or electrochemical, battery had been improved over the years, it still was a rather difficult (and costly) way to power a lamp. It did not deliver the quantity of electricity that was needed for a reasonable price without hassle. Although the public was flabbergasted by all those inventions exhibited to the public at exhibitions, the technical development of the filament as a vehicle for creation of electric light slowed down in the 1850s.

Then in the 1860s came the dynamo and especially the self-exciting dynamo. The need for cheap and abundant electricity was provided by the electric dynamo developed by Wheatstone, Varley, and Siemens. It was this dynamo that could supply cheap electricity in abundance. Thus, the need for electricity could be provided for. So in the 1870s all over the world (that is, from the United States to Russia), many inventive engineering scientists started focusing on the incandescent lamp. The arc light had sparked a massive interest with the public, paving the way, but had its (technical) drawbacks. With electricity now available in abundance, the concept of bridging the "voltaic gap" by a filament was picked up again.

The development trajectory of the incandescent lamp

Thus, a development effort to cross the "voltaic gap" with a thin wire (in this case, platinum) was undertaken. Certainly the heated wire created a glow, but it would not last too long (minutes). Placing the filament in an open vessel of glass did not solve the problem. To protect the filament from burning (oxidation), it was placed within a glass globe filled with helium. That was marginally better (life span: hour). Changing from metal to uncoated cotton thread and thin carbon filaments and placing it in a vacuumized closed vessel improved the life span considerably (to a dozen hours or so). Further optimizing the design elements (better vacuum, high-resistance carbonized bamboo filament, screw-in mount) resulted in the Edison lamp, a design that would dominate the electric light for decades. Further improvement related to the coating of the bulb, using tungsten for

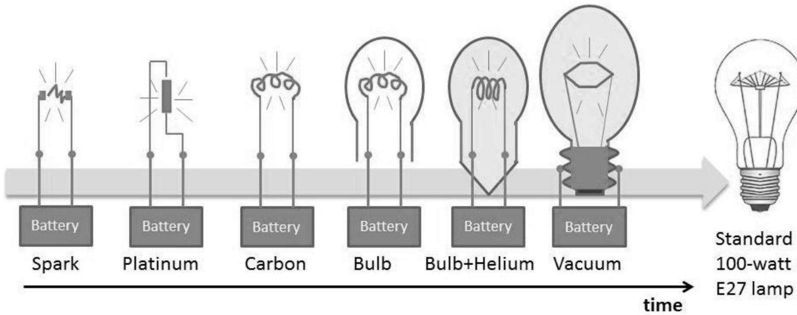

Figure 116: Development trajectory of the incandescent lamp.

a filament, argon as a gas.

Seen in its totality (Figure 116), the development of the incandescent lamp was a stream of innovations, some quite identifiable by their patents (King, Swan, Sawyer-Man). It was Edison who created the dominant design of the incandescent lamp and patented it. But he did more: he designed the system of electricity supply and distribution around it, thus creating the impact in the marketplace. (For more details see (Friedel & Israel, 2010)

All these development activities resulted in a wave of patents for a range of different "lightbulbs," each having its own characteristics, with advantages and problems of its own. This development culminated in the Edison incandescent lamp that was patented in 1880. The structured efforts of Edison and his team at Menlo Park had paid off, the publicity machine had made it well-known to the world, and the impact of the demonstration projects was huge. However, the protection offered by patent '898 was challenged: in court by other inventors who claimed priority, and by other manufacturers who copied the idea shamelessly. It resulted in a massive patent battle.

The Edison lamp was of a design that created a standard, not only from a technical point of view, as it also became a dominant factor in the market. It was followed by a range of other developments that either copied its design (during the invalidity of patent '898) or tried to circumvent the patent. When the patent expired, others picked up on the development and improved upon the concept, which would start a life cycle for the artifact "incandescent lamp" that would last into the twenty-first century. Then the solid-state version of the filament (the light-emitting diode or LED) would replace it.

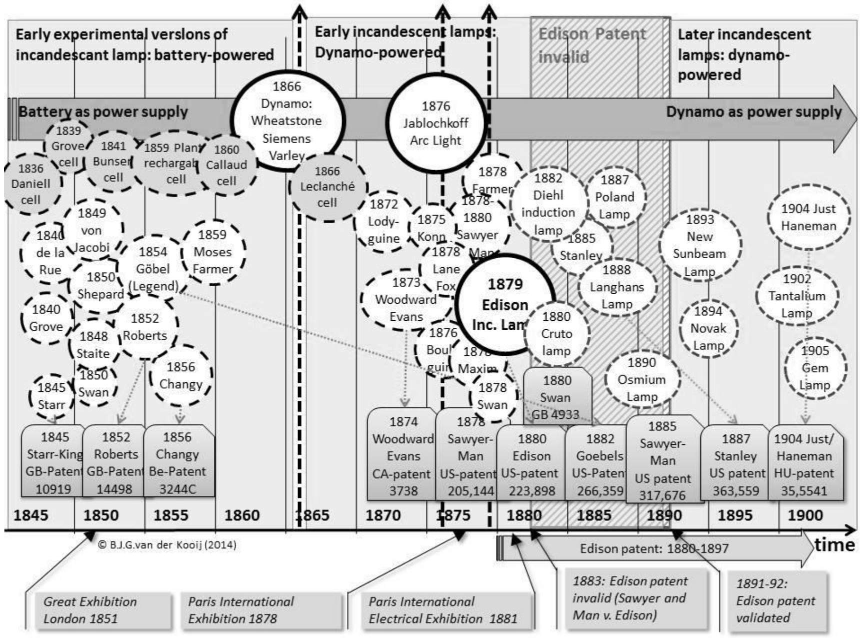

Figure 117: The cluster of innovations for the incandescent lamp in relation to their power supply.

The development of the supporting technology of the battery is separately indicated. Also, the basic innovations of the dynamo and arc light are shown as reference.

Source: Drawing by author.

It was clear that the development of the incandescent lamp, from its early beginning as glowing wire, leading up to the dominant design of Edison's lamp (Figure 117), would continue into a whole range of developments to improve upon the incandescent lamp. This trajectory would lead to the Tungsten lamp, for example. It created a technological trajectory that would last another 125 years, when the "inefficient" incandescent faded out.

Patent activity

All the described activities, experiments, and developments for the incandescent lamp resulted in a range of patents indicating the innovative activity. In Table 21 and Table 22, an (indicative) overview is given of those patents that can be considered as being more or less important for the development of the incandescent lamp up to Edison's '898 patent. They represent the development trajectory leading up with all the contributions that led to the dominant design of Edison's lamp, protected by US-Patent №. 223,898 (see descriptions in the tables for details).

Table 21: Overview of patents for the incandescent lamp during the period 1846–1880.

Patent № [1]	Year	Patentee	Description
GB 10,919	May 4,1846	J. W. Starr/King	Improvements in obtaining light by electricity
GB 3,809	December 14, 1872	A. Lodyguine (S. W. Konn)	Electric light/Semi-incandescent lamp
CA 3,738	August (?) 1874	H. Woodward, M. Evans	Electric light: Gas-filled lightbulb
US 166,877	August 17, 1875	S. A. Kosloff	Electric light: An electric current passes through and heats sticks of carbon placed in the circuit and hermetically closed in a globe filled with nitrogen gas (filed on June 23, 1875)
US 181,613	August 29, 1876	H. Woodward, M. Evans	Improvement in electric lights: Gas-filled lightbulb (filed on January 4, 1875)
US 194,500	August 21, 1877	W. Sawyer	Improvement in electric candles: The electric current to heat to incandescence a platina wire or wires, by the bearing of which against, preferably, white refractory substances, such as clays, lime, etc. (filed on June 22, 1877)
GB 4,933	November (?) 1880	J. Swan	Electric light/Semi-incandescent lamp: Low-resistance filament with parchmentised thread (filed on January 2, 1878)
US 205,144	June 18, 1878	W. Sawyer, A. Man	Improvement in electric lamps: Method to improve a practically operative lamp: The globe and stopper lamp (filed on May 16, 1878)
US 212,851	March 4, 1879	Ph. Jenkins	Improvement in electric lights: A hollow spherical, hemispherical, or spheroidal body, made of platinum or other suitable material, said body to be brought to incandescence by closing the electrical circuit upon it (filed on October 22, 1878)

Note 1: The indicated date is the granting date for US patents and the filing date for GB patents. Source: USPTO.

The preceding activities by other certainly contributed to Edison's '898-patent. Step by step they the practical problems related to bridging the "voltaic gap" with an incandescent wire. But it was Edison who succeeded in creating a workable and saleable artefact. His patent application (Figure 118) was for the dominant design that he wanted to protect with a patent.

Figure 118: Edison's patent application for the incandescent lamp.

Source: http://media.nara.gov/media/images/19/28/19-2765a.gif

The development of the incandescent lamp did not stop after Edison's incandescent lamp. Many inventors continued working on designing an incandescent lamp, either to circumvent Edison's patent or to improve upon it. This was not only the case in the United States, but also in Europe, where numerous companies started developing incandescent lamps.

Table 22: Overview of patents for the incandescent lamp during the period 1846–1880 (continued)

Patent № [1]	Year	Patentee	Description
US 213,643	March 25, 1879	M. G. Farmer	Improvement in electric lights: A transparent globe having its mouth closed airtight by a stopple of rubber or other elastic nonconducting material, two conducting bars or plates passing through said stopple, in positions parallel, or nearly so (filed on November 20 1878)
US 214,636	April 22, 1879	Th. Edison	Improvement in electric lights: regulating the electric current passing through such incandescent conductor automatically and preventing its temperature rising to the melting point, thus producing a reliable electric light (filed on October 14, 1878)
GB 4,576	October 21, 1879	Th. Edison	Electric lamp containing a loop of carbonized sewing thread filament mounted in an evacuated bulb
US 223,898	**January 27, 1880**	**Th. Edison**	**Electric lamp: Incandescent lamp with high resistance, carbonized bamboo filament in high vacuum in all-glass envelope**

Note 1: The indicated date is the granting date for US patents and the filing date for GB patents. Source: USPTO.

In the following Table 23, Table 24, and Table 25, an overview is given for the patents identifiable that were granted after Edison's patent. They represent the technology trajectory that was started by Edison's design.

Table 23: Overview of patents for the incandescent lamp during the period 1880–1891

Patent №	Year (1)	Patentee	Description
US 223,898	**January 27, 1880**	**Th. Edison**	**Electric lamp: Incandescent lamp with high resistance, carbonized bamboo filament in high vacuum in all-glass envelope (filed November 4, 1879)**
US 225,594	March 16, 1880	J. H. Guest	Electric lamp: To prevent leakage of air into the chamber through the openings made by the unequal expansion of the glass and metal at the points where the wires pass to the outside (filed January 9, 1880)
US 227,386	May 11, 1880	W. Sawyer	Electric lamp: "Stopper lamp" (filed March 26, 1880)
US 229,335	June 29, 1880	W. Sawyer	Carbon for electric lights: Carbon consolidated and purified by electrically treating it (also assigned to Man, Electric Dynamic Light Company) (filed November 22, 1878)
US 229,476	June 29, 1880	W. Sawyer	Electric switch: Device to regulate the application and division of the current to the lamp (also assigned to Man, Electric Dynamic Light Company) (filed December 5, 1878)
US 230,953	August 10, 1880	M. Maxim	Electric lamp: Improvement consists in displacing the air contained in the transparent globe with a liquid hydrocarbon, preferably gasoline, and then expelling such liquid by heat and exhausting the globe, so as to leave in it a hydrocarbon vacuum or a highly attenuated atmosphere of hydrocarbon vapor surrounding the conductor or light-giving part of the lamp (filed October 4, 1878)
US 233,445	October 19, 1880	J. W. Swan	Electric lamp: To prevent the cracking and leakage of the glass bulb or enclosing vessel in consequence of the heating and cooling of the conducting-wires, which, when simply sealed into the glass globe, cause it to crack and leak at or near the junction of the wires and glass (filed April 12, 1880)
US 234,345	November 9, 1880	J. W. Swan	Electric lamp: An exceedingly solid homogeneous and elastic form of carbon, peculiarly adapted for the formation of arches, spirals, or other forms of conductor for electric lamps, can be produced from cotton thread that has been subjected to the action of sulphuric acid (filed .June 16, 1880)

Note 1: The indicated date is the granting date for US patents and the filing date for GB patents.

Source: USPTO.

Table 24: Overview of patents for the incandescent lamp during the period 1880–1891 (continued)

Patent № [1]	Year (1)	Patentee	Description
US 244,277	July 12, 1881	M. Maxim	Electric lamp: Invention to provide an high-resistance incandescent lamp adapted to be used in series and capable of giving a large amount of light (filed December 8, 1880)
US 244,291	July 20, 1881	Ch. Perkins	Electric lamp: Employment of independent carbon clips that are secured to the incandescent strip and are adapted to it tightly in platinum cups or sockets carried by the conducting wires (filed February 4, 1881)
US 247,097	July 20, 1881	J. Nichols	Electric lamp: Method of mounting the carbons or connecting them with the wires (filed April 18, 1881)
US 250,192	November 29, 1881	L. Böhm	Electric lamp: The use of straight carbons and to facilitate the introduction of the carbons and sealing of the wires (filed July 15, 1881)
US 250,227	November 29, 1881	E. M. Fox	Electric lamp: Improvements consist in the form of the glass chamber, in combination with the conducting wires, the holders for the carbon, and a reflector; and also, further, in the peculiar form of carbon (filed May 21, 1881)
US 251,540	December 27, 1881	Th. Edison	Electric lamp: Fibrous carbon for electric lamps: Filaments made out of carbonized bamboo or similar fiber (filed August 8, 1880)
US 251,774	January 3, 1882	St. George Lane Fox	Electric lamp: to improve the connection between the luminous bridge and the conducting wires or terminals, and at the same time to prevent leakage of air into the lamp (filed June 15, 1881)
GB 3,494	August 28, 1880	St. George Lane Fox	Electric lamp; To improve the connection between the luminous bridge and the conducting wires or terminals, and at the same time to prevent leakage of air into the lamp (see US 251,774 for similar patent)
US 255,277	March 21, 1882	Ch. H. Gimingham	Electric lamp: Improvements relate to a method of cheaply and readily manufacturing incandescent lamps, and to the mounting of carbon filaments of electric lamps generally (filed December 23, 1881)
US 258,976	June 6, 1882	A. Bernstein	Electric incandescent lamp: To produce an electric lamp that has the advantage of increased durability and illuminating power, owing to the fact that substances are employed that are capable of resisting the action of strong currents (filed December 24, 1881)

Note 1: The indicated date is the granting date for US patents and the filing date for GB patents.

Source: USPTO.

Table 25: Overview of patents for the incandescent lamp during the period 1880–1891 (continued)

Patent №	Year (1)	Patentee	Description
US 266,358	October 24 , 1882	Henry Goebel	Electric incandescent lamp: The carbon conductor is secured into the flattened and spirally coiled ends of the metallic conducting wires and cemented thereto (filed January 23, 1882)
US 266,741	October 31, 1882	E. Weston	Incandescent electric lamp: Method of mounting the carbons of incandescent electric lamps in which flat strips of flexible carbon are employed as the conductors (filed July 19, 1882)
US 276,571	May 1, 1883	P. Diehl	Incandescent electric lamp: The light is produced in vacuo by the inductive action of an exterior condenser plate on an interior condenser plate, the induction currents obtained thereby being of sufficient strength either to pass from one carbon to another or to heat a continuous carbon filament to incandescence (filed Dec. 13, 1882)
US 317,676	May 12, 1885	W. Sawyer, A. Man	Electric light: Electric lamps employing an incandescent conductor enclosed in a transparent hermetically sealed vessel, from which oxygen is excluded (filed January 9, 1880)
US 335,158	February 2, 1886	E. Thomson	Incandescent electric lamp: Lamp with incandescent strip or rod, whereby the continuity of the general circuit may be preserved when the lamp is removed from its socket or when the carbon breaks, so that an incandescent lamp may be used in series with other incandescent lamps or with arc lamps (filed January 2, 1883)
US 370,993	October 4, 1887	E. Thomson	Incandescent electric lamp: Leading-in wires across from one to the other by means of a temporary bridge, which, upon becoming heated by a sufficient current, melts, and thus interrupts the connection between the two wires (filed September 15, 1886)
US 444,530	January 13, 1891	Thomas Edison	Leading-in wire for incandescent lamp: To economize in the amount of platinum employed and at the same time to provide a seal around the leading-in wires that shall be as nearly perfect…while at the same time an effective support for the filament (filed September 15, 1890)

Source: USPTO.

Industrial bonanza: The incandescent-lamp manufacturers

The impressive developments that resulted in Edison's landmark invention were a stimulus for massive business development. Many companies started manufacturing of incandescent lamps (Figure 119). Some of these were companies already active in a related field (like the arc light), while others (like some foreign companies) were new entrants to the market. There were also many new start-ups clustered in areas like Cleveland.

In 1879 Charles Francis Brush had put Cleveland on the lighting map when he demonstrated his arc lamp. However, following the success of Thomas Edison's incandescent lamp, also in 1879, manufacturers of arc lamps realized that they could not ignore this development. It was not an issue of just expanding into other arc-light markets (like Brush creating the

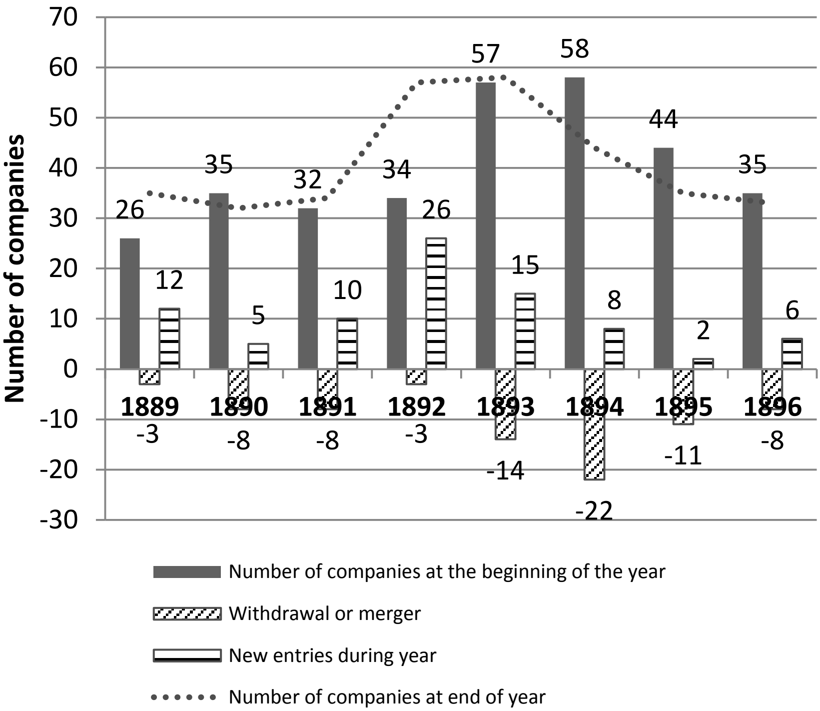

Figure 119: The number of active incandescent-lamp manufacturers in the United States by year

Source: The Electrician, Electrical Trades' Directory and Handbook, Vols VII–XVI, London, 1889–1897 (Bright, 1949, p. 92).

*Anglo-American Brush Electric Light Corporatio*n in England[108]), but also an issue of getting into the business of incandescent lamps.

Eluhi Thomson's "electrical business" activities

At Thomson-Houston Co., it was decided to go into the incandescent-lamp business, but that took a while. The cause for the delay was that Coffin became interested not only in the incandescent lamp, but also in the AC system that was becoming more and more a factor in the generation and distribution of electricity. Thomson-Houston was in 1885 quite successful with their arc-lighting system, in which they could connect several arc lamps to one generator. To expand on these local systems, Coffin wanted to apply central stations, and the concept of the central station worked fine with AC.

> *During a trip to Europe in 1885, Coffin saw a demonstration of an AC system developed by the Hungarian inventors Zipernowsky, Blathy, and Deri (ZBD). Although Coffin always claimed that he knew nothing of the intricacies of electrical technology, he quickly realized from the ZBD system that alternating current could be used to build central stations in smaller cities and towns. On his return, he urged Thomson to pursue his work with induction coils and to file additional patent applications for parallel circuits as soon as possible. Through late 1885 and early 1886, Thomson tested an AC system.* (W. B. Carlson, 1995, pp. 78-79)

It was not before mid-1886 that Thomson ran a local experimental system. The competition, in this case Westinghouse, had already proved their approach to the AC-incandescent lighting in March 1886, when Stanley demonstrated the system in Great Barrington, Massachusetts. In November 1886 Thomson sold their first system in Buffalo.

> *Thomson…was determined to introduce a complete AC system, with generators, regulators, lamps, transformers, and safety devices all matched to each other, and designing such a system would take time. He believed that an AC system designed as a single entity would be the most reliable; to quote him again, "when we enter this field we wish to…be sure of success from the start with a complete and economical system, and the preparatory work that we have done will, we think, tell in the end.* (W. B. Carlson, 1995, pp. 80-81)

Implementing this vision of Thomson took time in the development process to implement AC systems, but there was more that happened in 1887, and it was related to patents.

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[108] It was the Dutchman Gerard Philips who, after working for the Anglo-American Brush Company, started in 1891 the manufacturing of incandescent lamps at Philips & Co. (later 'Philips Gloeilampenfabriek').

> *In 1887 Thomson-Houston launched a comprehensive attack against all who had infringed the patent for Thomson's dynamo regulator. That campaign helped wear down several of Thomson-Houston's major arc-lighting competitors and facilitated the acquisition of those firms by Thomson-Houston. Similarly, Westinghouse sued Thomson-Houston in 1887 for infringing its Gaulard-Gibbs transformer patent, leading to a patent-sharing agreement with Thomson-Houston.* (B. W. Carlson, 1993, p. 283)

It was Thomson-Houston against Westinghouse, and patent infringement was the game. But they solved their problems with a patent-sharing agreement.

> *Westinghouse gained an important advantage over Thomson-Houston by securing a broad patent for an AC distribution system with transformers in parallel. In contrast, all of Thomson's patent applications for AC distribution were rejected in the fall of 1886. This put the Thomson-Houston Electric Company in the defensive position of having to contest or else bypass the Westinghouse patent…During a meeting of the American Institute of Electrical Engineers in March 1887, Thomson met with Pope and discussed the desirability of cooperating rather than competing in the AC field. After several meetings, officials from Thomson-Houston and Westinghouse reached an agreement in August 1887. In return for a license to sell Thomson-Houston arc-lighting equipment, Westinghouse allowed Thomson-Houston to manufacture AC systems without fear of infringing the Westinghouse AC distribution patent. Although this agreement was terminated within two years because the Westinghouse patent was ruled invalid in court, it did give Thomson-Houston time in 1887 and 1888 to improve its AC equipment…In May 1887, the firm shipped its first AC machine to the Lynn Electric Lighting Company, and by the year's end it had installed twenty-two more systems.* (W. B. Carlson, 1995, pp. 80, 81, 82)

Thomson Houston's strategy was to gain a dominant position in the electric business, and arc light was part of that: "Between 1888 and 1891 Thomson-Houston spent $4 million purchasing control of seven firms in the arc-lighting and street-railway field" (B. W. Carlson, 1993, p. 292). He was not the only one, as Westinghouse did the same: "Westinghouse bought out the United States Electric Lighting Company and the Consolidated Electric Light Company for their incandescent-lamp patents and the Waterhouse Electric Light Company for its arc-lighting system" (Ibid.).

Then the arc-light companies entered the incandescent-lamp business and became the domestic competitors to the new incandescent-lamp manufacturers.

> *But they also had to beat foreign competition. This as the result of the formation of the Swan Incandescent Electric Light Company of New York in 1882 when the Brit Swan tried to market the Swan lamp system in the United States. Brush formed, with a license from Swan, in 1885 the Swan Lamp Manufacturing Corporation in Cleveland. This was just one of the many incandescent lamp manufacturers that were created in this area, especially after the expiration of Edison's patent in 1894. Like the Buckeye Electric Company (1890), the Adams-Bagnall Electric Company (1895), the Universal Electric Company (1893–1896), the Fort Wayne Lamp Company (1897–1899), the General Incandescent Lamp Company (1899) and the Royal Incandescent Lamp Company (1898). Elsewhere other companies were already created: the Langley Electric Light Company (1881), the Hawkeye Electric Manufacturing Company (1886?), the Shelby Electric Company (1896). In cities like Warren, Ohio many incandescent lamp manufacturers were being established: the New York & Ohio Company (1891), the Warren Electric & Specialty Company (1893), and in the period 1904–1908 another dozen companies. The same happened in other regions. Like in 1889 the Sunbeam Incandescent Lamp Company of Chicago, Fostoria Incandescent Lamp Company in Ohio in 1897.* (Covington, 2013a, p. Nela)

There was fierce competition between the independent manufacturers and the large companies, which resulted in a competitive battle that drove prices below the cost of manufacture. So, due to these problems, many merged into a friendly consolidation that created the *National Electric Lamp Company* (NELA) in 1902 (with the help of General Electric, who became a silent partner, putting up 75 percent of the capital needed for a 25 percent stock option). Finally, this company was acquired in 1911 by *General Electric Company*, exercising its option to buy 25 percent of the stock in 1911.

> *The National Electric Lamp Company was formed in 1901…The unusual consolidation allowed National to set up laboratories so that all companies that joined the consolidation were free to use the results generated through testing. The individual companies could not afford such facilities. Thus, all companies could receive laboratory results but still remain competitors of the other companies. The idea behind this bold move was simply to compete on the basis of quality…From the standpoint of the small companies, they had the best of all worlds. They continued to operate as though they were independent but they could benefit from the laboratories at the National headquarters in Cleveland. The plan worked—lamp quality eventually reached high levels. In addition, the member companies of National became formidable "competitors" of the General Electric Company. When National was formed, the lamp output from all the companies amounted to*

> *about 20% of the total lamp production—with General Electric accounting for 80%. However, the ratio was about 50-50 by 1910.*[109]

The same thing happened in Europe, where in Britain, Edison's patent domination had kept the competition at bay until after 1893. Then a succession of companies appeared: the *Incandescent Electric Lamp Co. Ltd.* (1893), the *Bernstein Electric Lamp Company, Ltd* (1894), the *Crystal Electric Lamp Company, Ltd* (1895), the *British Incandescent Lamp Company, Ltd* (1896), and the *Sunbeam Lamp Company, Ltd.* (1887). In Germany, in addition to *AEG* and *Siemens & Halske*, numerous small firms started: the *Rheinische Gluhlampenfabrik Dr.M. Fremery & Co* (1892), the *Fabrik elektrischer Gluhlampen Agnes Roeder & Co.* (1894), and *Fleischhacker & Co.* (1895) (Heerding, 1988, pp. 39-40).

It was a process where, in this market hungry for incandescent lamps, new companies were created, struggled to create a position in the marketplace, lost the battle of competition, and went bankrupt or merged into other companies. By 1890 Edison, Thomson-Houston, and Westinghouse were the "Big 3" of the American lighting industry. In 1892 J. Pierpont Morgan engineered a merger between the Edison interests and Thomson-Houston. The resulting company was named *General Electric*. That brings us back to Edison and his entrepreneurial activities.

Thomas Edison's "electrical business" activities

Edison had created, with his college friend Franklin L. Pope in 1869 and the publisher J. N. Ashley, his first company, *Pope, Edison & Co.,* as an independent inventor (Figure 120). Next they organized the *Financial & Commercial Telegraph Company,* using the stock ticker developed by Edison, to supply gold and stock quotations to mercantile and importing firms in Manhattan. Within half a year, they sold it to Gold & Stock, together with the just-created *American Printing Telegraph Company*. Then in 1870, the companies *Newark Telegraph Works* and *American Telegraph Works* were created. These were the first business activities of a long range of companies that would follow. This is not to say that Edison managed and financed all those companies himself. Many of them were patent licensing firms that were allowed to use his name. But all the companies were more or less directly related to his inventive work

> *Edison was certainly not content to be just an inventor, a person who turns ideas into patents. He believed that a patent was hardly worth the trouble of inventing something. He knew from experience that selling patents to businessmen often left the inventor shortchanged. More often than not the returns from a new idea went*

[109] Text source: http://home.frognet.net/~ejcov/nelapark.html.

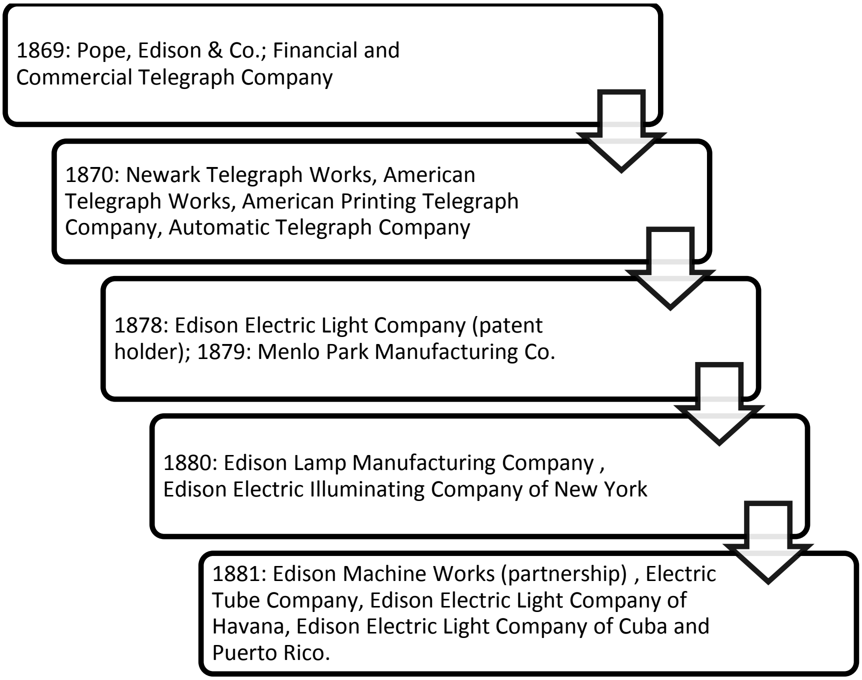

Figure 120: Successive companies based on the electric dynamo and systems, lamps, and telegraph patents of Thomas Edison (1883–1889).

Source: http://edison.rutgers.edu/list.htm#Lightdom.

> *to the financier or manufacturer, while the inventor struggled to protect his patent in the courts and obtain his share of the profits. A patent alone was not enough, nor was an invention. The original idea had to be developed into something more tangible than a patent; it had to be transformed, or "perfected" into a working model or a final product—something a businessman could see and touch rather than imagine. This was essential to obtain financial support…He pursued the policy of expansion without regard to the overall development of the organization, forming new companies and building factories as the need arose. Each new product led to a new company and often to a new manufacturing facility.* (Millard, 1991, pp. 192, 195)

Considering his business to be in "electric light," this started after he, in his laboratories at Menlo Park, New Jersey, demonstrated his incandescent lightbulb in December 1879. It fascinated the visitors, who were used to candle lights and gaslights. Edison is supposed to have said: "We will make electricity so cheap that only the rich will burn candles."[110]

Just before this he had created, on November 15, 1878, the *Edison Electric Light Company*, which financed his electric-light experiments in return for control of the resulting patent.

> *The corporation was a Wall Street organization and contained among its list of incorporators several of the firm of J. Pierpont Morgan and Company. Half of the $300,000*[111] *capital was made available to Edison to equip his laboratory for investigation…The Edison Electric Light Company wanted to remain simply a holder of patents and licensor of installations of the Edison system, and not go into manufacturing.* (Speiden, 1947, pp. 140, 141)

Incandescent lamps were being manufactured by the *Edison Lamp Company* (originally *Edison Lamp W*orks, later *Edison Electric Lamp Company*), a partnership among Edison, Charles Batchelor, Edward H. Johnson, and Francis R. Upton. It was in 1878 that Edison, with twelve other individuals, created the *Edison Electric Light Company of New York* as a licensee for the Pearl Street project, financially backed by the Morgans' and Vanderbilts' bankers (Figure 121). He also created the *Edison Machine Works* to produce dynamos, the *Edison Lamp Works* to produce lamps, the *Edison Tube Company* to manufacture the underground storage pipes,

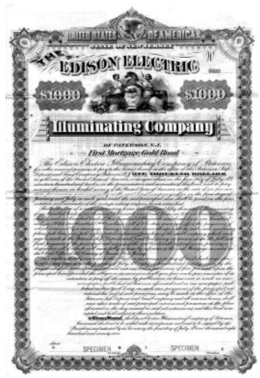

Figure 121: Certificate from the Edison Electric Illuminating Company (printed in 1892).

Source: www.scripophily.net/edelilcoxx.html.

Figure 122: Interior of Building 12 of Edison Machine Works in Schenectady (1891).

Source: www.schenectadymuseum.org/edison/a_timeline/images_02/f02_03.htm.

[110] Source: http://edison.rutgers.edu/latimer/tae1.htm.

[111] This investment would be equal in 2010 to $45,300,000.00 (using the unskilled wage) or $73,400,000.00 (using production worker compensation). Source: http://www.measuringworth.com.

and *Sigmund Bergmann and Co.* to provide lighting fixtures and small electrical components [112].

The further development of his entrepreneurial activities, were characterized by many mergers and acquisitions (Figure 123,).

In **1883** the Edison Machine Works (manufacturing dynamos) had already absorbed the Edison Shafting Company and the Edison Tube Company.

At the beginning of **1886** the manufacture and sales of Edison electrical equipment was being conducted by five separate companies. Then two further changes were made. The parent Edison Electric Light Company absorbed the Edison Company for Isolated Lighting. In addition, the Edison United Manufacturing Company was formed to consolidate the work formerly done separately by the Edison Lamp Company, the Edison Machine Works and Sigmund Bergmann & Company and to act as selling agent for all the Edison manufacturing plants.

In **1889** another merger took place. It was J. P. Morgan who initiated the merger of Edison's electricity related US-companies (like the Edison Lamp Company, Edison Machine Works, Bergmann & Company) with the patent holding Edison Electric Light Company and thus created the Edison General Electric Company. In 1889 it acquired the Sprague Electric Railway and Motor Company. When in 1892 the competitors Thomson-Houston Electric Company and Edison General Electric Company merged, the nowadays still existing company General Electric was created. It was with this merger that J. P. Morgan and his allies wrested full control of Edison General Electric from Edison and his supporters, in a leveraged buyout through competitor Thomson-Houston.

It was not only mergers that occurred. It was also expansion that characterized Edison's entrepreneurial activities in the 1880s. By 1888 the *Edison Light Company* and its subsidiaries all over the country had negotiated with the local authorities hundreds of franchises for permission to string electric cables and build power plants (Granovetter & McGuire, 1998).

[112] For more information about Edison Companies: The Thomas Edison Papers. Edison Companies by Industry. Electric Light, Domestic. Source: http://edison.rutgers.edu/list.htm#Lightdom

Business generation

It was not only Edison who was active in business; others took the opportunities offered by the new technologies and the enormous market potential. So companies were created to exploit the new opportunities related to electric light. It started with arc-lighting companies, and the same method of operation was followed by the incandescent-light companies. Among those were the companies that would become the electric utility industry.

> *Each operating company was typically given an exclusive license under the patents of a manufacturing company for a particular territory. In return, it paid a block of stock and a sum in cash to the parent patent-holding company. In addition, the operating company bought most needed equipment from the parent company or its affiliates.* (Bright, 1949, p. 74)

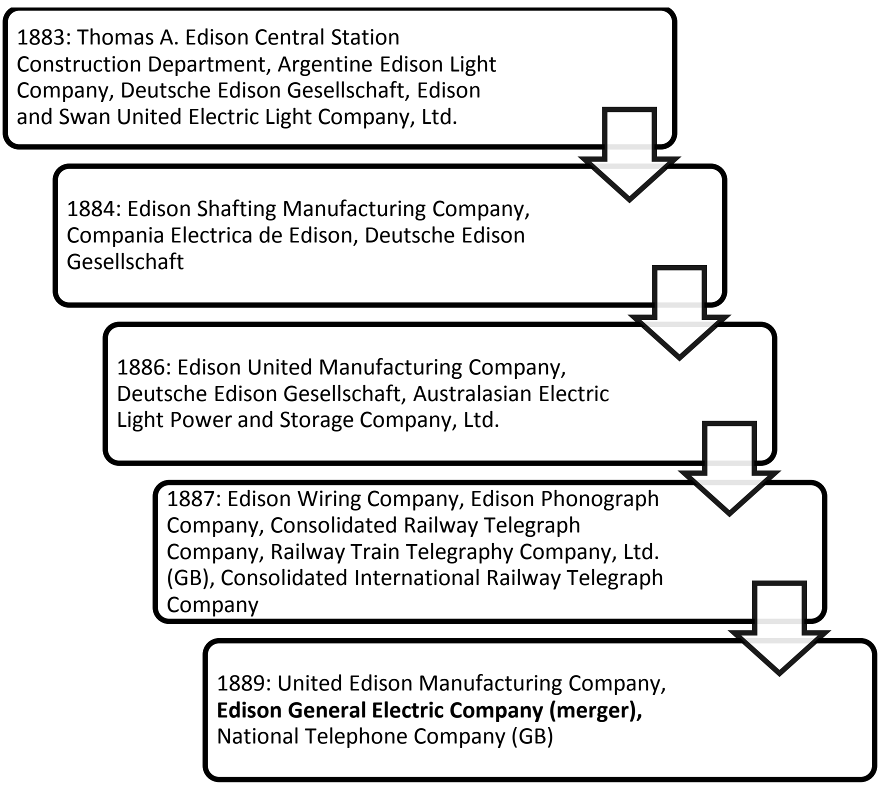

Figure 123: Successive companies based on the electric dynamo and systems, lamps, and telegraph patents of Thomas Edison (1883–1889).

Source: http://edison.rutgers.edu/list.htm#Lightdom.

The supplier of electricity needed equipment, which they acquired from the "equipment manufacturers": companies making the new systems that were protected by their patents. This was what Thomas Edison did when he created companies to exploit his patents: the *Edison Electric Light Co.* (1878), the *Edison Lamp Manufacturing Company* (1880), and the *New York Edison Electric Illuminating Company* (1880).

> *The success of the New York undertaking led to the formation of a dozen more local Edison companies by the end of 1883, and within three more years fifty-eight Edison central stations providing current for 149.900 incandescent lamps were in operation in this country.* (Bright, 1949, p. 75)

It was the same pattern that was followed by other companies—like the Brush companies—(if they could finance this method of operation). Soon companies were created that were only manufacturing incandescent lamps, often without having a patent position of their own. They were mostly small enterprises that tried to obtain a small part of the market dominated by the Edison companies.

> *By 1885 all those American manufacturers who could be called pioneers in the field of incandescent illumination had initiated their operations. Throughout the remainder of the 1880's about twenty additional concerns began to produce filamentary electric lamps. Although a few of these later entrants were arc-lighting or other electrical-goods manufacturers who were interested in expanding their lines, most of them were small concerns organized for the primary purpose of making incandescent lamps. They were the imitator firms which typically spring up when it is possible to exploit a new discovery or invention. They did not produce complete lighting systems, only lamps for use with systems sponsored by other producers. Their entry was encouraged by the expanding market, the favorable profit prospects, and the fact that only a few thousand dollars were required for establishing a new company. Despite the fact that lamp production was arduous and required meticulously careful work, one good engineer could bring to a company almost all the necessary technical knowledge for setting up in business.* (Bright, 1949, pp. 77-78)

Thus, the new phenomenon of electric light gave rise to a new industry, like the telegraph and telephone did in the field of communications. Companies that created electric systems manufactured the generators of electricity, the (incandescent) lamps, and all the different accessory products related to them (i.e., switches, fuses, and cables). Some companies just manufactured parts of the system: a generator or an incandescent lamp. And some companies simply generated the electricity and distributed it, thus creating the electric utility industry. Table 26 shows some of the principal companies in this new cluster of businesses.

Table 26: Principal pioneer manufacturers of carbon-filament lamps in the United States (1880–1885)

Company	Start production
Edison Lamp Company	1880
United States Electric Lighting Company	1880
Weston Electric Light Company	1881
Consolidated Electric Light Company	1882
Brush Electric Lamp Company	1883
Union Switch & Signal Company	1883
Bernstein Electric Light Manufacturing Company	By 1884
American Electric Manufacturing Company	By 1884
Thomson-Houston Electric Company	1884
Swan Lamp Manufacturing Company	1885

Source: (Bright, 1949, p. 72).

In the United States, on-site electric lighting systems had been sold and installed as early as 1878, and by 1885 were a booming business involving over 1,500 arc and incandescent systems operating in homes and factories. Alongside these "isolated plants," a fledgling industry of privately owned central electric stations blossomed from less than two dozen firms in 1882 to almost five hundred in 1885 and almost two thousand independent local firms by 1891, using different technologies and organizational structures (Granovetter & McGuire, 1998).

From there the electric applications expanded. It was a time of the "wild west" in the industry, with many competing systems having their own characteristics (e.g., voltage) and lacking any form of standardization. All those companies needed to be financed.

> *The development of electric motors for street railways, electrified steam railroads, elevators, factory machinery, and many other uses greatly expanded the scope of the industry within a few years. When first organized, each of the manufacturing companies typically specialized in a single field…Companies grew so rapidly that they had difficulty in financing their expanded business without constantly bringing in new money. At the same time, many of the concerns desired to expand into new lines of production. The pressure of all these factors, particularly financial needs and patent conflicts, coupled with the natural competitive urge to expand and the spirit of trustification then prevalent in American industry, precipitated most of the corporate mergers and reorganizations in the electrical-goods industry between 1882 and 1896.* (Bright, 1949, p. 79)

Merging Thomson-Houston Electric & Edison General Electric

In the 1880s a struggle was going on for the incandescent-lamp industry. The expansion of business was tremendous, but patent infringement cases and financing problems made life difficult for the start-ups. Many folded or were acquired by stronger companies. The period of 1880–1890 was quite turbulent. The Edison companies were dominant, Thomson-Houston its only real competitor. By 1892 Thomson-Houston was comparable in size to Edison General Electric, with sales offices located in a dozen principal cities (Table 27).

> *In 1892, Thomson-Houston, a firm with about 4.000 employees, its plant at Lynn, and its headquarters in Boston, was merged with Edison General Electric, then a firm with 6.000 employees, two plants (the New York factory was moved to Schenectady in 1891), and its headquarters in New York. The new firm which resulted, the General Electric Company, thus had about 10.000 employees and plants at Schenectady, Harrison, and Lynn.* (Passer, 1952, p. 382)

Table 27: Comparison of Edison General Electric Company and Thomson-Houston Company (1891)

	Edison General Electric	Thomson-Houston	Total
Capitalization	$15,000,000	$10,400,000	$25,400,000
Gross business	10,940,000	10,304,500	21,244,500
Profits	2,098,000	2,700,000	4,798,000
Number of employees	6,000	4,000	10,000
Factory space (sq. ft.)	400,000	340,000	740,000
Customers	3–4,000	3–4,000	6,000
Central stations	375	870	1,245
Isolated installations	2,300	very few	over 2,300
Street railways equipped	180	204	384
Street railway cars	2,230	2,760	4,990

Source: (Bright, 1949, p. 94).

At the end of the 1880s, both *Edison General Electric Co.* and *Thomson-Houston Electric Co.* were active in the electric business.

> *The conviction was taking shape that the incandescent lamp and the alternating-current transformer system belonged together, just as did the overhead trolley and the magnetic blowout. The two were complements of each other. Yet they had been kept apart because the patents were held by rival concerns. It was found that no plant could be constructed and no system installed by either company with any hope of rendering efficient service to the public without infringing the rights of the other company. In many of the larger cities two rival electric lighting systems*

> *existed. One local company exploited the Edison low-tension direct-current method of incandescent illumination; the other operated the Thomson-Houston high-tension alternating-current arc-lighting circuits and series incandescent circuits.* (Hammond, 1941, p. 192)

In 1892 the two companies merged and created the company *General Electric*, which would go and dominate the electric industry in the next decade.

> *So passed into one corporation two great undertakings. In resources and in achievements, the merging companies were almost equal. The Edison company was capitalized for $15.000.000; Thomson-Houston for $10.400.000. The Edison Company reported a gross business of $10.940.000 for the preceding year; Thomson-Houston showed a gross of $10.304.500. There were 6000 employees on the Edison rolls, 4000 on the Thomson-Houston. The Edison Company had two manufacturing plants fourteen acres, forty buildings, and 400,000 square feet of floor space. The Thomson-Houston Company had one plant covering eight acres, with eleven buildings and 340,000 square feet of floor space. Both had between 3000 and 4000 customers each. The Edison Company had approximately 375 central-station companies, and more than 2300 isolated lighting installations. Against this showing Thomson-Houston reported 870 central-station companies, but very few isolated plants. The Edison Company had equipped 180 street railways and 2230 cars; the Thomson-Houston 204 roads and 2760 cars.* (Hammond, 1941, pp. 194-195)

By that time most of the original inventors were not active anymore in their companies. Charles Brush had, after Brush Electric was acquired by Thomson-Houston in 1889, sold his interest in Brush Electric. He, being a wealthy man, moved on to other fields of endeavor, never to return to the electric industry. In 1881 Hiram Maxim moved to England, where he started a workshop near Hatton Gorden, London. In 1883 he invented the Maxim machinegun and was granted a British patent for it. After becoming a British subject in 1899, he was knighted by Queen Victoria in 1901 for his inventions, many of which had a military application.

> *Elihu Thomson went along with the new company as consulting engineer and head of the Lynn research laboratory. He was the only one of the leading early inventors who was active in the new company; he declined a proffered directorship in order to continue his laboratory work unimpeded. Thomas Edison remained inactive, although he continued as a director. All the other pioneer inventors who had been affiliated with the numerous predecessor companies by that time had retired or had become interested in other activities.* (Bright, 1949, p. 96)

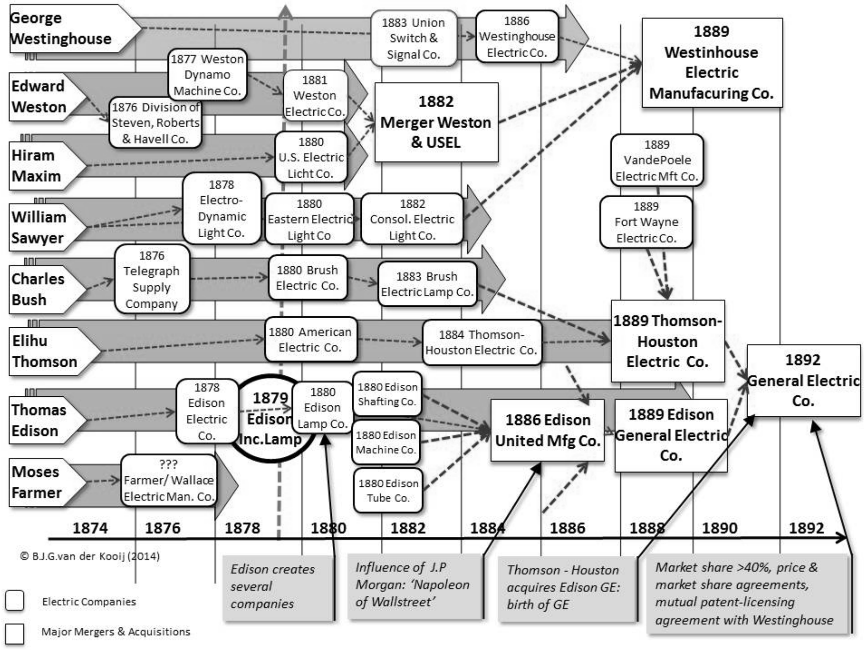

Figure 124: Mergers and acquisitions in the incandescent-lamp manufacturing

Inventors (left column) and their companies related to the major mergers.

Source: Figure created by author.

The result of all these mergers and acquisitions was that, in the beginning of the 1890s, there were two big companies active in the electric industry: *General Electric Compa*ny (as the merger of Thomson-Houston Electric Company and Edison General Electric Co.) and the *Westinghouse Electric Manufacturing Co.* (Figure 124). General Electric became a dominating force in the field of electric lighting, but it was not restricted to that market segment.

> *It was during the years of greatest financial stress, from 1893 to 1896, that the struggle for commercial superiority in the incandescent-lamp business was going on. Similar struggles were taking place in the fields of electric traction, alternating-current generation and distribution, and arc lighting. In all fields General Electric adopted an aggressive patent policy. It wanted to control as large a portion of the American electrical-goods business as possible. While many competing companies put up a vigorous defense, General Electric was able to establish itself firmly as the dominant firm in the industry, supplying more than half the domestic market*

for almost all non-communications electrical items. Even though a number of individual companies survived, they found it extremely difficult to do more than maintain their positions with respect to the leader. The aggressive policies employed by General Electric during the nineties resulted in some popular reaction against the big company, however. Public antitrust agitation was directed against it as early as 1893, based upon its attempts to use the Edison patent to regain absolute control of the incandescent-lamp market and to broaden its control in other branches of the industry. Similar attacks were made later, and around 1910 they resulted in a prosecution by the federal government under the Sherman Anti-Trust Act of 1890. (Bright, 1949, pp. 97-98)

Conclusion

Anno 2015 it is hard to image a world without electricity. Only when, due to failures in the supply system, one realizes how dominant "electricity" has become. If the "electricity" is lost, the social and professional life slowly comes to a halt. Shops, factories, restaurants, but also stop lights, traffic signs, airports, hospitals, they all cease to function properly. Electricity is taken for granted, electric technology is the unnoticed part of our daily lives. But it took nearly two centuries to make all that possible. And the foundations were laid in the nineteenth century.

In the preceding segment we have looked at two application fields of the General Purpose Technology of 'electricity'. We have identified its three major clusters of innovations; 1) the cluster around the *basic-innovation of the Arc Light*, and 2) the cluster around the *basic-innovation of the Incandescent Light*. Our major theme was the quest into the Nature of Innovation. More specifically we focused on innovation related to electricity. How could these two basic innovations revolutionize the world we live in today? Creating an utter dependence of societies on a single phenomenon called 'electricity'. Giving us all the comforts of electric light and the electric domestic appliances. Facilitating our modern tele-communications and fulfilling our information needs. What did it make happen to be?

Just reflecting on the massive social changes that originated from the contributions of so many, willing to devote their creative efforts in changing the world, we will try and wrap up this case study with the following interpretations of our observations.

Human curiosity, ingenuity, and competition

The discovery and application of the electric light (both arc and incandescent) certainly could be an invention if it had been the act of one person. But that was not the case, as shown in the preceding overview. It was a range of discoveries made by many inventors that started with "electromagnets" and at the end created the range of lights and motors we use today. It took a while to come from Volta's pile (ca. 1800) through Jablochkoff's arc light to Edison's incandescent light.

As these were applications that used electricity, the supply of electricity by the electrochemical battery (the "wet cell") was limiting. For the further application of electric light and electric power, the development of the electric dynamo (the "dry cell") was decisive. Now that electricity could be easily generated in abundance, a range of events occurred. It was this breakthrough of the magnetoelectric dynamo that, fueled by development in the lighting applications, created increasingly complicated networks of electric-power distribution. Starting with the problematic arc lights, the discovery of the incandescent lamp fired further developments rapidly. Electricity, especially the alternating current electricity that could be easily transported over large distances, became a general power source for light applications.

Curiosity into the nature of light

It all started with curiosity, people asking themselves questions. Why did things happen as they did? Why did the frightening lightning in the sky occur, and why did it have such a loud noise and deadly force? Can we get hold of it, bringing it to earth? Can we imitate it when we rub a cat's fur against an amber stick?

And then came the "wett cell"; Volta's discovery of the new phenomenon of "electricity" as the result of a chemical process. It gave rise to a new range of questions. What happens if we hold the two wires of a battery close? What is that glowing effect of a wire when a large current passes through it? What happens if we create a thin filament? Combining the creativity to experiment, the inquisitive looked for answers. In short, many curious people asked themselves the question of what was the nature of light and how could we use it.

Slowly insight was created into the nature of light. Insight created by the collective curiosity of all those inventive people spending their time and money experimenting. Maybe even without understanding the reasons why, the "engineering scientist" started exploring the phenomena related to the newfound "electric light" (Figure 125). Not only could a current from a bank of voltaic cells spark into light, as Humphry Davy and Vasilii Petrov demonstrated. It could also—after much experimenting—be controlled and maintained for a longer period. It were both the spark and the filament crossing the ”voltaic bridge” that sparked their curiosity and created a stimulus to explore their new findings—like Faraday discovering that magnets could induce electricity.

As said, it was the magnetoelectric dynamo that created a breakthrough. Basically the discovery of the dynamo effect was quite simple. It was people like Faraday and Lenz who discovered that, as electricity could create movement (the dynamoelectric machine or electro motor), it also worked the other way: rotative movement of a coil in a magnetic field could create electricity. It would be the antagonist of the dynamoelectric machine (or dynamo, as it later became named), that lifted the obstruction caused by the wet cell. This “dry cell” generating electricity in abundance was the newfound source of electricity. Then, in the *era of light*, electric lighting created the “market pull” that complemented the “technology push.” People were fascinated by the demonstrations of the new arc lights lighting streets and theatres. And when the incandescent lamp was developed, enormous lighting markets fueled further developments. From simple

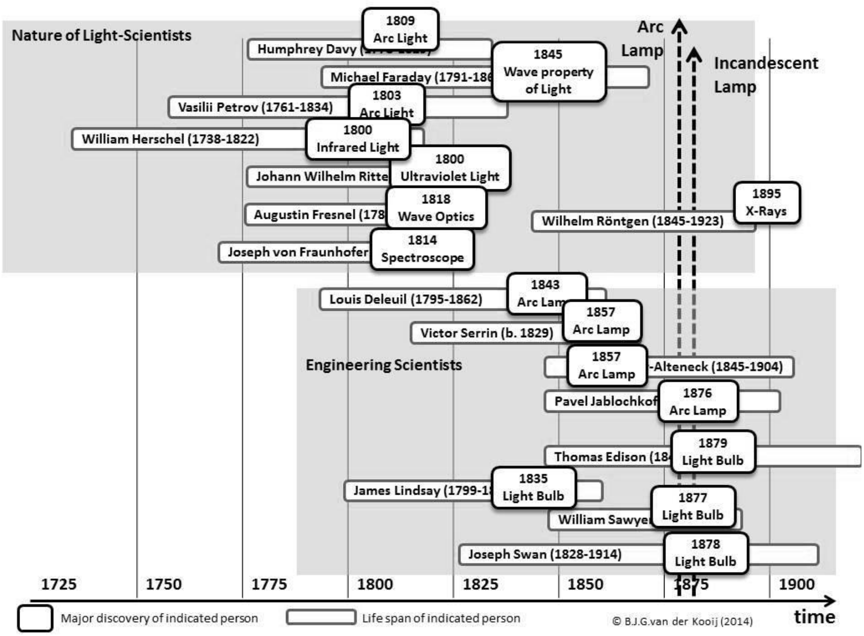

Figure 125: Engineering scientists bridging the voltaic gap by arc and filament.

Source: Figure created by author.

locally based DC-electricity distribution networks to larger municipal DC-electricity networks, electricity became available on a larger scale.

Ingenuity

Many individual scientists, inventors, and engineers contributed to the total development (Figure 126). Some contributions had a small impact; others had an influence that changed the course of the development. Although mostly dominated by the technological potential of electricity to transport power, the developments took place in a specific context of the nineteenth century, a context that was dominated in the United States by its capitalism, resulting in massive business creation and monopolies by giant companies. In a totally different context in many European countries, each with its own character, similar developments took place, also leading to massive business generation and giant companies.

Remarkably enough, the electric light grew to maturity in a short period of time. Jablochkoff's invention of the arc light (1876) and Edison's invention of the incandescent light, were both with the 1870s. Although that was the pioneering time of electric light, soon the diffusion of the

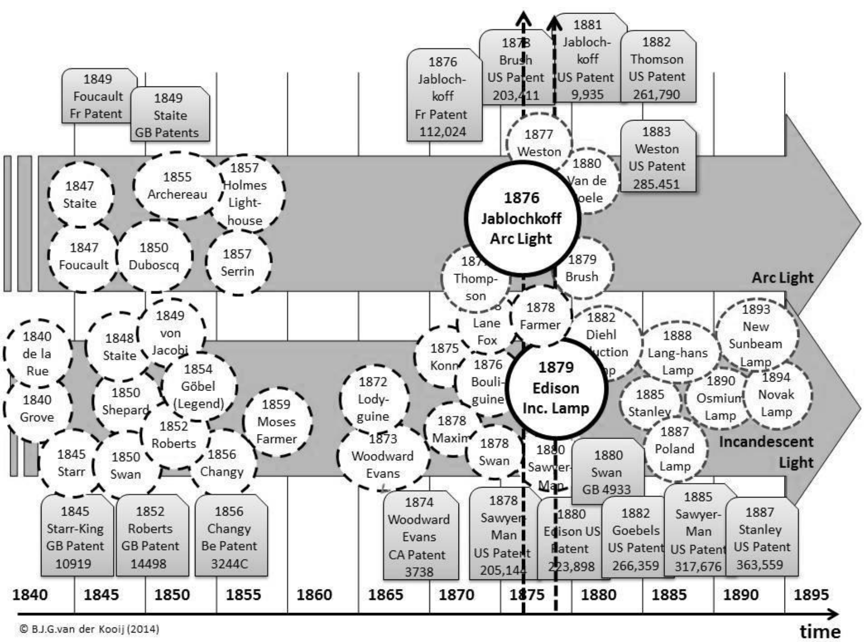

Figure 126: Overview of clusters of innovations for the arc light and the incandescent light.

Source: Figure created by author.

electric technologies and the application of electric light in daily life would follow. It took, however till the end of the nineteenth century. And in every phase of its development, individual people contributed to its application. Some from the technical side, developing and manufacturing the components and the systems. Others from the application side, solving the problems of the application of the new devices and systems.

Competition

All these contribution took place in an competitive environment. Competitive in the scientific world where 'being the first to invent' was considered to be important. But also in the entrepreneurial world where the enterprising individuals converted concepts into products and systems. Often with great individual sacrifice (material and immaterial), and sometimes with considerable financial rewards. The development of electric light took place in the specific context of the nineteenth century—a context that was dominated in the United States by its capitalism, resulting in massive business creation and monopolies. Electrical light progressed in a totally different context in many European countries, each with its own character. Yet similar developments took place, also leading to massive business generation and giant companies. Electric utilities began to spring up in major cities during the 1890s, and by the 1900s they were spreading rapidly across the U.S and over Europe. Their initial major field of interest was the electric light.

Soon it became clear that electricity was too important for governments to stand aside. Government introduced regulation for safety and reliability, stimulated standardization, even took an active role in the creation and distribution of electricity (first on a municipal level, later on regional and state level). Fundamental principles justified governmental oversight of the utility sector. Since a utility provides essential services for the wellbeing of society — both individuals and businesses — it is an industry "affected with the public interest." And regulation was intended to protect the "public interest." But it left the application of the electric light to the market. It was the electric equipment industry that responded to the massive demand for electric light.

The context for the equipment manufacturers may have been different between the Old World of today's Europe and the New Word of North America, they had one element in common; competition for survival. Certainly the capitalist system has been creating a highly competitive structure for individuals and organizations to earn an existence and survive. But also the more socially oriented European system had competitive elements where individual and organizations were faced with. Both systems, each in its own way, was about the Darwinian "survival of the fittest". The fittest technology, the fittest company, the fittest products. A process in which technologies, companies, infrastructures, systems and products were created, pioneered, matured and died. A process of business cycles with its creative synthesis and creative destruction.

Social change induced by technical change

What can be observed from our exploration into the specific 'electric light' application of the General Purpose Technology of 'electricity'? How can we interpret the relations between social change and technical change? Let's try and identify some of the characteristics.

Second Industrial Revolution: "There was light"

The European Revolutions of 1848 mark the different periods of social, technical and political change. The first half on the nineteenth Century was still dominated by the *First Industrial Revolution*. The second half of the nineteenth Century was to be dominated by the *Second Industrial Revolutution*. First in England where the *Great Victorean Boom* (1850-1873) took place.

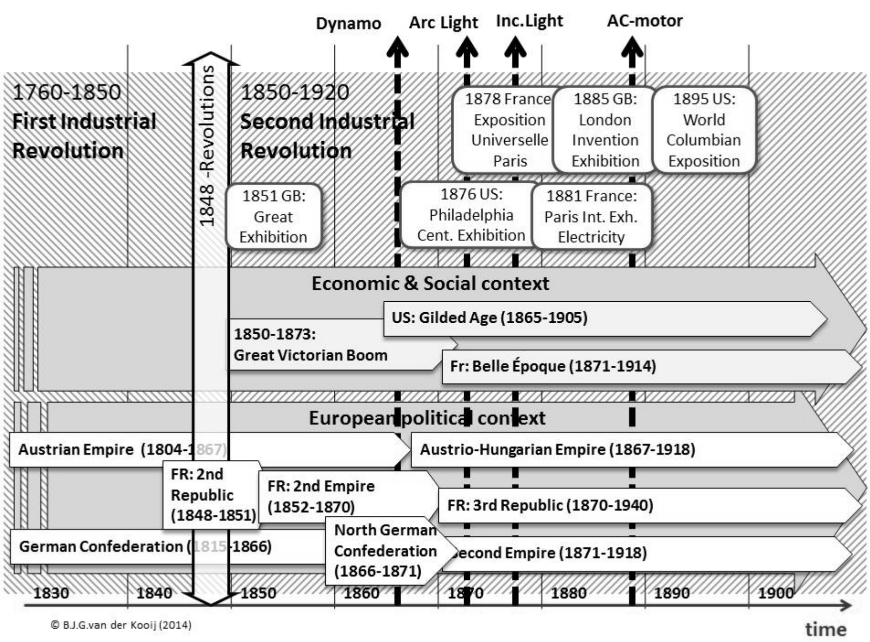

Figure 127: The context for the Electric Revolution

Source: Figure created by author

Then, after the dust had settled on the madness of times that ruled Europe for so long and the new political structures were in place, a period of relative peace commenced, in which economies and societies bloomed. It was the time for the *Belle Epoque* in Europe (1871-1914) . The same goes for the US where, after the end of the Civil War, the *Gilded Age* (1865-1905) illustrated the prospering country (Figure 127).

The second half of the nineteenth century heralded the start of the Electric Revolution, but in was not until the second half of the twentieth century that electric light became became the norm in households and businesses. In just one century, America and Europe went from no electric lighting to nearly complete electric lighting. This rapid proliferation led to fundamental changes in private life—where and when people gathered, where and when they could work. Industrialization was influenced, not only as the result of "electric power", but also the lighting of factories influenced working hours and safe working conditions.

Public awareness

Imagine the person from the preelectric era being confronted with the new thing called electricity. The wonders of electricity were shown to the astonished public at exhibitions like the *Great Exhibition of the Works of Industry of all Nations* (the Crystal Palace Exhibition) in London in 1851, drawing more than 6 million visitors. The 1876 *Philadephia Centennial Exposition* drew nearly 10 million visitors, watching the wonders of steam technology, Alexander Bell's telephone, and the Farmer-Wallace electric dynamo. The *Exposition Universelle* in Paris in 1878 with 13 million visitors, the *International Exhibitions of Electricity* in Paris in 1881, and the *London Inventions Exhibition* in 1885 with 3.3 million visitors—they all created a massive public interest in the electric light, from arc light to the incandescent lamp (next to other miracles such as the telegraph, telephone, and phonograph).

The early demonstrations of the arc light in Philadelphia, Holborn Street (London, England), and l'Opera (Paris, France) and those demonstrations of the incandescent lamp at Menlo Park and Pearl Street (New York, USA) excited the public and spurred the early entrepreneurs into action. The *International Electro-technical Exhibition* in Frankfurt in 1891, the *World Columbian Exposition* in Chicago in 1893, and the *Niagara-project* in 1895 were milestones in the development of AC systems. From there on the penetration of electricity in society became a fact.

Pervasiveness

Our preelectric person certainly would have problems envisioning the role of electricity as it developed in the twenteeth-first century. It was hard then to foresee its development, like in the private environment of the home, where dozens of lamps and light armatures would create “light in the darkness,” where dozens of small motors in a range of appliances (e.g., a battery-powered alarm clock) would be working without the user even realizing its presence. How could one foresee a working environment dominated by tools using DC motors, like handheld tools (battery-powered drills)? And finally, how could our preelectric person foresee that living and working conditions would be influenced so dramatically by the use of electricity at home and in business—the electric light?

The electricity that powered all these applications is supplied by a system of interconnected electricity-distribution networks: regionally, nationally, and internationally. Electricity generating plants are powered by hydroelectric, nuclear, gas, and coal “prime movers,” thus creating a society that totally depends on one single phenomenon: electricity. It is a fragile existence, as one realizes the problems caused by the Tohoku earthquake and tsunami that destroyed the nuclear power plant of Fukushima, Japan, on March 11, 2011. It was a disaster that, in addition to the immediate destructive effects of the tsunami itself (18,500 deaths or missing, 300,000 evacuated, some 125,000 buildings totally destroyed[113]), resulted in a major drop in the electricity supply, causing major economic stagnation in Japan.

Business development: clusters of businesses

This case study related to the development of the electricity. Focusing on the electric light, there are two basic innovations, the arc light and the incandescent lamp, that fueled its development. These basic innovations were based on the work of many individuals (Figure 126). Some were contributing to conceptual and theoretical insight; others—being more of a practical nature—contributed with their engineering skills, transferring the concept into working artifacts. It took time, as there was not one single moment and one single person that had the magic eureka moment that created the invention. The early contributors to the described development were *gentlemen of science*, more or less privileged persons curious about the “nature of lightning.” Other contributors were the *electriciens*, persons not always gifted with theoretical insight, but with the endurance to overcome practical problems and able to create working artifacts. And there were the innovator-entrepreneurs, who created the enterprises that manufactured the

[113] Source: Damage Situation and Police Countermeasures. http://www.npa.go.jp/archive/keibi/biki/index_e.htm

actual machines. Many inventors became entrepreneurs, exploiting their own inventive work.

The totality of all these efforts resulted in several bonanzas of entrepreneurial activity: each basic innovation one's own, different in its actual form, but nevertheless characterized by business activity, new start-ups, fierce competition, mergers, and acquisitions. Electric lamps were applied in such a broad range of applications that the manufacturing of electrical lamps became a major industry.

Assuming one could distinguish the total development into different phases—in modern conceptual thinking: research phase, development phase, and innovation phase—an indication could be given of the different phases between the initial "idea" and the final "saleable product." As phases and artifacts do overlap, Table 28 shows only that the time between the conception of the early principles and the implementation into grown-up applications is considerable.

Table 28: Development in phases for major innovations in electric light

	Research Phase	**Development Phase**		**Innovation Phase**
	Early principle	Early prototype	Early products	Saleable product
Arc Lamp	1800+	1840–1860	1860–1876	1876–1880
Incandescent Lamp	1840–1860	1872–1877	1877–1882	1882–1885

Basic innovations: Patents and their impact

Each of the basic innovations had its own contributing innovations and resulted in the incremental innovations that followed it, innovation often protected by patents. Some patents were for innovations that did not have an impact; other patents resulted in frantic infringement cases and patent wars. The issue of who had priority was a matter of honor and pecuniary consequences. Looking at the totality of the nineteenth century, Table 29 presents those patents that were quite basic (directly or indirectly) in the development of the arc lamp and the incandescent lamp.

Table 29: Patents for basic innovations in the electric light

Patent №	**Year**	**Patentee**	**Invention**
Fr №. 112,024	1876	P. Jablochkoff	Electric Arc Light
US №. 223,898	1880	Th. Edison	Electric Incandescent Lamp

To conclude

The developments described had an enormous impact on society, not only in the nineteenth century, but up till today. The innovations created were the result of a stepwise and complex process, as was made clear by Oliver J. Lodge (1851–1940), a professor of physics who participated in the discovery of electromagnetic waves, in his lecture about "The relation between electricity and light" at the London Institute on December 16, 1880. He started by saying:

> *Ever since the subject on which I have the honor to speak to you to-night was arranged, I have been astonished at my own audacity in proposing to deal in the course of sixty minutes with a subject so gigantic and so profound that a course of sixty* lectures *would be quite inadequate for its thorough and exhaustive treatment…*
>
> *Now, then, we will ask first, What is electricity? and the simple answer must be, We don't know. Well, but this need not necessarily be depressing. If the same question were asked about matter, or about energy, we should have likewise to reply, no one knows…But to the question. What is electricity? we have no answer pat like this. We can not assert that it is a form of matter, neither can we deny it; on the other hand, we certainly can not assert that it is a form of energy, and I should be disposed to deny it. It may be that electricity is an entity per se, just as matter is an entity per se…*
>
> *Now we will pass to the second question: What do you mean by light? And the first and obvious answer is, Everybody knows. And everybody that is not blind does know to a certain extent. We have a special sense organ for appreciating light, whereas we have none for electricity. Nevertheless, we must admit that we really know very little about the intimate nature of light—very little more than about electricity.*(Lodge, 1881, pp. 302, 303)

After a lengthy discourse and many demonstrations on the development of the understanding of the nature of electricity and light—including the role of people like Maxwell, Faraday, and many others—he concluded:

> *I have now trespassed long enough upon your patience, but I must just allude to what may very likely be the next striking popular discovery, and that is the transmission of light by electricity; I mean the transmission of such things as views and pictures by means of the electric wire.* (Lodge, 1881, p. 306)

He was absolutely right and would prove himself that even the wire was not needed when he gave another lecture at the British Association for the Advancement of Science at Oxford University in August 1894. But that is another story[114].

The era that started with the curiosity of many about the nature of electricity (and light) and that created, after experiments by others just as curious, the "electric candle" and the "electromotive engine" changed society in ways hardly anyone from preelectric times could have predicted. The famous biblical expression "And there was Light" (Gen. 1:3) could not have been more applicable than to all the efforts of so many creative people in the second half of the nineteenth century: "There was light."

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[114] See: B.J.G. van der Kooij: *The invention of Communication Engines*. (2015)

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Drs.Ir.Ing. B. J. G. van der Kooij (b. 1947) in 1975 obtained his MBA (thesis: Innovation in SMEs) at the Interfaculteit Bedrijfkunde (nowadays part of the Rotterdam Erasmus University). In 1977 he obtained his MSEE (thesis: Microelectronics) at the Delft University of Technology.

He started his career as assistant to the board of directors of Holec NV, a manufacturer of electrical power systems employing about 8,000 people at that time. His responsibilities were in the field of corporate strategy and innovation of Holec's electronic activities. Travelling extensively to Japan and California, he became well known as a Dutch guru on the topic of innovation and microelectronics.

In 1982–1986 he was a member of the Dutch Parliament (Tweede Kamer der Staten Generaal) and spokesman on the fields of economic, industrial, science, innovation, and aviation policy. He became known as the first member to introduce the personal computer in Parliament, but his work on topics like the TNO-Act, Patent Act, Chips-Act, and others went largely unnoticed.

After the 1986 elections and the massive loss for his party (VVD), he was dismissed from politics and became a part-time professor (Buitengewoon Hoogleraar) at the Eindhoven University of Technology. His field was the management of innovation. In 1986 he started his own company, Ashmore Software BV, developer of software for professional tax applications on personal computers.

After closing these activities in 2003, he became a real estate project developer, and in 2009 a real estate consultant till his retirement in 2013. Innovation being the focus of attention all his corporate, entrepreneurial, political, and scientific life, he wrote three books on the subject and published several articles. In his first book, he explored the technological dimension of innovation (the pervasive role of microelectronics). His second book focused on the management of innovation and the human role in the innovation process. And in his third book, he formulated "Laws of Innovation" based on the Dutch societal environment in the 1980s.

In 2012 he started studying the topic of innovation again. In 2013 he was accepted at the TU-Delft by Prof. Dr. Cees van Beers as a PhD candidate. His focus is on the theory of innovation, and his aim is to develop a multidimensional model explaining innovation. For this he creates extensive and detailed case studies observing the inventions of the steam engine, the electromotive engines, the information engines, and the computing engines. He studies their characteristics from a multidisciplinary perspective (economic, technical, and social).

Van de Kooij is married and spends a great deal of his time working in the South of France.