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PART I

CONCEPTS

1

The Invention and Spread of Electric Utilities, with a Measure of the Extent of Foreign Ownership

Electricity is essential, but it was not always so. The vast benefits, as well as dependency, electricity has brought to the contemporary world are never more dramatically demonstrated than when a blackout occurs. In economically developed countries, even brief blackouts cause severe inconvenience, and extended blackouts can impose huge economic costs and even lead to breakdowns in civil order. In less developed countries, blackouts tend to be chronic, inhibiting economic growth and social progress.[1] Two massive blackouts, each affecting over 50 million people, occurred in August and September of 2003, one engulfing the midwestern and northeastern United States and part of eastern Canada, the other affecting most of Italy – the largest blackout in Europe since World War II.[2] These blackouts demonstrated both the importance of electricity and the imperfection of the industry that delivers it. As the final report of the task force investigating the U.S.-Canada failure noted, "Modern society has come to depend on reliable electricity as an essential resource for national security; health and welfare; communications; finance; transportation; food and water supply; heating, cooling, and lighting; computers and electronics; commercial enterprise; and even entertainment and leisure – in short, nearly all aspects of modern life."[3] Nitin Desai, Secretary General of the United Nations' World Summit on Sustainable Development (Johannesburg, 2002) emphasized the importance of electricity both for today and for the future: "Electricity has profoundly transformed the industrialized world and led from the era of smoke chimneys into the era of knowledge-based services shaping the 21st century .... Universal access to affordable energy services including electricity is a prerequisite for achieving the goals and objectives of sustainable development .... Electricity permeates every aspect of

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economy and society."[4] Some observers anticipated the tremendous potential for electricity to transform the world – not just illuminate streets and homes – during the earliest days of the industry. An article in the *New York Times* of January 17, 1881, noted a full year and a half before Thomas Edison's pioneering Pearl Street station commenced operation: "That the remarkable tendency shown by inventive genius during the past ten years toward the application of electricity to the needs of modern life continues is a fact which is receiving fresh illustrations almost daily ... Never before were so many men of genius at work in shops and laboratories trying to harness the new force in the service of man, and never was capital more eager to meet the inventor half-way and push his schemes through the channels of business enterprise. Electric companies for lighting houses and thoroughfares, for supplying motors, and for innumerable other purposes are springing up with a rapidity that is marvelous."[5] This book describes the role of multinational enterprise and international finance in making global electrification possible.

Where does the world stand now in terms of global electrification? The use of electricity and the extent of electrification can be measured in different ways. Total production of electricity varies widely among countries. In terms of total national production, the United States dominates, with net electricity generation in 2003 of almost 3.9 trillion kilowatt hours (kWh), over twice the amount generated by the second largest producer, China, which produced 1.8 trillion kWh. Only one other country, Japan, produced more that a trillion kWh in 2003.[6] Two better measures of the relative importance of electricity across countries are per capita consumption (presented in Figure 1.1 for a selection of countries for 2001) and household access to electricity (presented in Figure 1.2 for 1984, the latest date for which comprehensive figures are available).[7] These measures highlight the vast discrepancies that remain between developed countries and less developed ones. The global electrification process, while highly successful in many countries, remains incomplete. Around two billion people, roughly one-third of the world's population, still do not have access to centrally generated electricity.[8]

Before we trace the role of multinational enterprise and international finance in global electrification, we offer a perspective on the underlying characteristics of the electric light and power sector. The chapter begins with the inventions and new technologies that made electricity possible. The capital intensity of this sector emerges, with its profound economic significance. The growth of the industry was accompanied by interventions by national and subnational governments, and we briefly discuss their roles. The growth in electricity usage is shown by aggregate production statistics, which closely paralleled consumption. At the end of the chapter, we present a table that is at the core of our study, showing by country changes over time in foreign ownership and control of electric

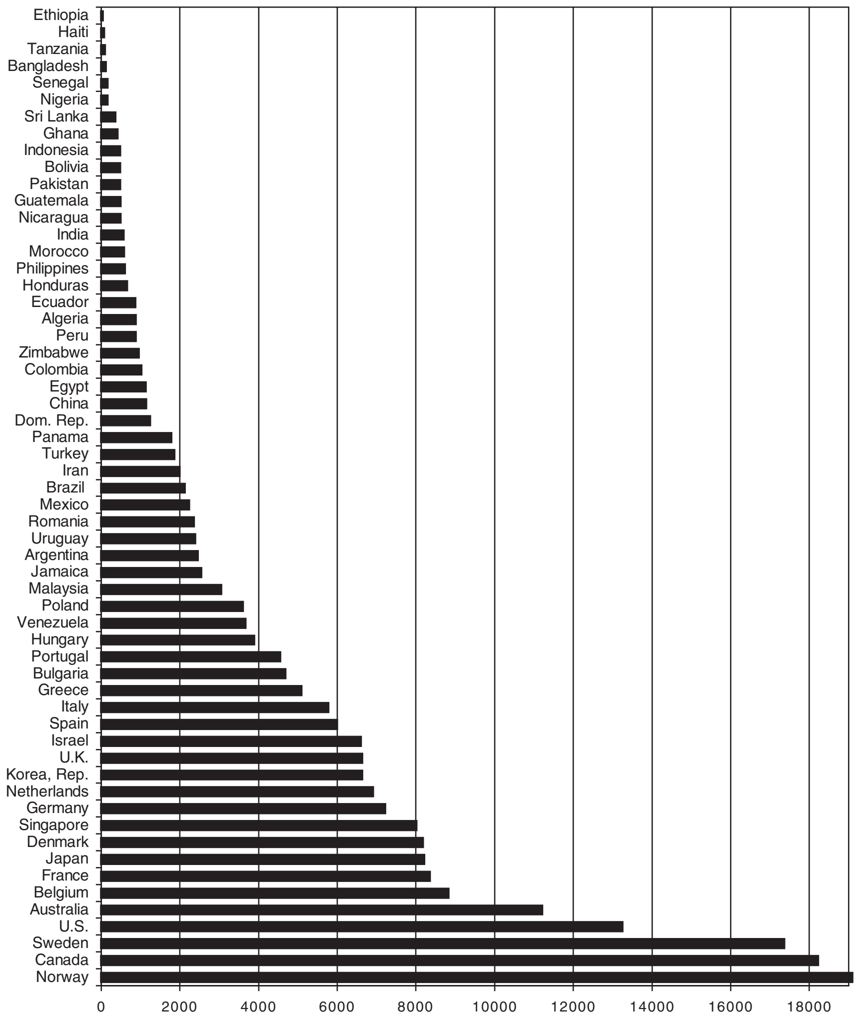

FIGURE 1.1. Per Capita Consumption of Electricity, Selected Countries, 2001 (kWh)
Source: United Nations Department of Economic and Social Affairs, Statistics Division, *Energy Statistics Yearbook* (2001) (New York: United Nations, 2004), Table 35, 478–94.

utilities. This table shows the importance of foreign-owned and -controlled firms (multinational enterprise) to the early diffusion of electricity. The table also reveals how in the course of time the role of multinational-enterprise activities were reduced (a process we call "domestication") until they were virtually gone by the mid-1970s. We consider the resurgence of foreign ownership of electric utilities over the past twenty years in Chapter 7.

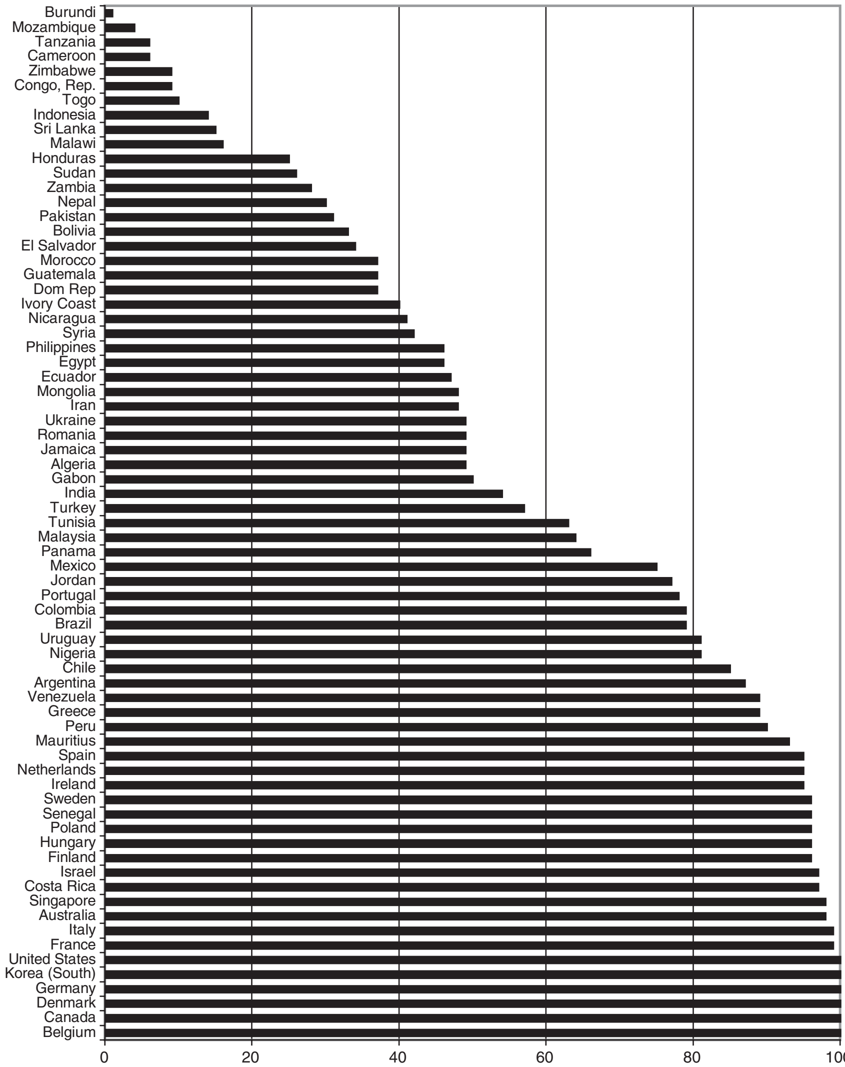

FIGURE 1.2. Percent of Households with Electricity, Selected Countries, 1984
Source: World Development Report 1994 (Oxford: Oxford University Press for the World Bank, 1994), 224–25.

THE PRECURSORS OF ELECTRIC LIGHT

The availability of a fully satisfactory form of artificial light is a relatively recent historical development: Until the middle of the nineteenth century, essentially all artificial light was obtained from some form of open flame. Ancient humans obtained light from fires and torches. The first great lighting innovation probably was the oil lamp, initially made from hollowed-out stones some 20,000 or so years ago.[9] The basic structure of the oil lamp, with its reservoir and wick, has remained essentially unchanged over the millennia, although many substances have been used as fuel, including both vegetable and animal oils. From the sixteenth through the nineteenth century, whale oil was a highly desirable fuel for lamp use. This was eventually supplanted by mineral oil, or kerosene, originally developed in the late 1840s and early 1850s by the Canadian Abraham Gesner and the Scotsman James Young. Kerosene became the dominant lamp fuel after the American Edwin Drake's successful oil discovery in 1859 led to an enormous expansion in the availability of the crude oil from which it was made.[10]

A variant of the oil lamp was the candle, whose origins are uncertain, but which is known to have been used by the ancient Romans. The first candles were made of either tallow (animal fat) or the superior, and hence more expensive, beeswax.[11] At the close of the eighteenth century, the use of spermaceti, obtained from the head of sperm whales, permitted an improved candle.[12] Candles remained a relatively expensive source of light until paraffin, a by-product of petroleum, became available.[13] All of these sources of light had one thing in common: They were stand-alone; none of them required a delivery network; none was provided by a "public utility," a term generally referring to a company or organization, either private or government-owned, that provides services to the general public over a network.[14] Electricity also could be and was provided by "isolated plants," essentially generators that were owned by the individuals or firms that used the power they produced.

The first public utilities devoted to illumination were gas lighting companies, which came to supply the main source of artificial light in urban areas for much of the nineteenth century, even into the twentieth century. The first gas lighting public utility was the Chartered Gas Light and Coke Co., which was granted a twenty-one-year charter by Great Britain's Prince Regent in 1812 to supply London and the surrounding boroughs.[15] By 1823, three different companies were supplying gas in the London area. Illuminating gas was manufactured by heating a fuel (usually coal, but also wood or oil) in the absence of air. The resultant gas could then be distributed in pipes to burners that initially produced open flames, like oil lamps or candles. Gas lights were convenient because they required substantially less attention and maintenance than the other forms of artificial light, and they became widely used for both interior and exterior (especially street) illumination. Although a number of refinements were made in the burners (or jets) over the course of the nineteenth century, the most dramatic innovation in gas lighting actually occurred after the development of the electric light. The gas mantle developed by the Austrian physicist Carl Auer von Welsbach in 1887 placed a solid substance in the flame that was then heated to incandescence, thus improving both the quality and the efficiency of gas lights. The Welsbach mantle gave gas lighting a powerful competitive weapon against the electric light and resulted in forestalling, and even in some cases temporarily reversing, the ultimate replacement of gas lighting by electric lighting.[16]

ELECTRICAL TECHNOLOGY AND THE BIRTH OF ELECTRIC UTILITIES

The path leading to the creation of the electric utility began in earnest at the start of the nineteenth century. The steps included discovery of the scientific principles of electricity, the invention of sources of power (the battery and dynamo), the creation of devices that effectively used electricity (lights and motors), devising a means of transmitting and distributing the electricity (especially over long distances), and finding a means of financing the whole operation.

The production of electricity with potential commercial applications did not occur until the invention of the battery by the Italian physicist Alessandro Volta in 1800. A battery (which Volta termed a "pile") produces a direct (or continuous) current of low voltage by chemical means. High levels of current (and/or voltage) could be obtained by connecting a number of batteries together. Soon after Volta's invention, the English scientists William Nicholson and Anthony Carlisle discovered electrolysis, the use of electricity to separate compounds into their elemental components by separating water into hydrogen and oxygen. By 1809, their compatriot Sir Humphry Davy had used more-powerful currents to isolate additional elements. This led ultimately to the discovery of electrochemical processes with significant commercial value, including electroplating and the smelting and refining of certain ores.

The significant technical breakthroughs that resulted in the creation of the electric utility industry came first in the field of electric lighting. Early electric lights were classified as either "arc" or "incandescent."[17] Sir Humphry Davy was a pioneer in both types of lighting. He demonstrated incandescent electric lighting in 1801 by using batteries to heat platinum strips. There is some evidence that Davy exhibited arc lighting the following year, and by 1808 he was able to provide a well-documented and impressive display of arc lights powered by two thousand battery cells to the Royal Institution in London. Davy's arc light essentially consisted of a continuous spark between two carbon electrodes, and all subsequent arc lights were based on the principles Davy discovered.[18] Incandescence requires that a material be heated, but it is difficult to maintain the stability of a substance at high temperatures because of its tendency to melt, vaporize, or oxidize. Most of the improvements in both incandescent and arc lighting involved methods of prolonging the life of the heated material. This initially proved easier to do when the heating was associated with a spark; thus, arc lights gained a slight lead over incandescent lights in becoming commercialized. Some of the earliest electric central stations, dating from the late 1870s, provided arc street lights in major world cities such as Philadelphia, San Francisco, New York, London, and Paris, as well as other cities.[19]

Electric power had a separate but related history. The electric motor's impact was destined to be profound, and the provision of electricity to motors, which were used to power machinery, played a major role in the industry. The first electric motor probably was produced in 1821 by the English scientist Michael Faraday, who had worked as a laboratory assistant to Davy, after learning of the discovery the previous year by Hans Christian Ørsted that a wire conducting electricity produced a magnetic field surrounding it. Faraday also discovered induction, the ability of a moving magnetic field to create an electric current. In 1831, he developed the first electric generator, a copper disk rotating between the poles of a magnet.

Electric lighting and power remained curiosities until powerful and efficient generators significantly reduced the cost of producing electricity. Stimulated by the potential for commercial success, improvements in the technologies of lighting, power, and generation continued to be made after the middle of the nineteenth century. Beginning in the mid-1850s, electric arc lights powered by steam-driven generators were used at construction sites in France and by the 1860s in lighthouses in both France and England. Generators slowly began to replace batteries in other applications of electricity, and the use of generator-powered arc lighting spread to other areas, including military signaling.[20] None of the electricity produced for these uses came from central-station utilities; all of these uses were satisfied with isolated plants.

A major factor hindering the first generators was the lack of strength of the permanent magnets they employed. Although designs incorporating electromagnets to help increase the strength of the magnetic field were tried as early as the mid-1840s, the major advance occurred with the discovery and publication of the principle of self-excitation virtually simultaneously by Charles Wheatstone, the brothers C. and S. A. Varley, and Werner Siemens in 1866–1867.[21] The iron core of an electromagnet retains some slight magnetism even when the current is off. This residual magnetism is enough to generate a small amount of current in a rotating armature, and when the armature is appropriately wired the current will increase substantially. Originally, the term "dynamo-generator" was used to distinguish this from the "magneto-generator," which used permanent magnets. Ultimately, the former term was shortened to "dynamo," which came to be applied generally to all electric generators.

One important technical aspect of producing electricity that later was to create controversy was whether direct or alternating current would be used. Although batteries always produce direct current, generators can be designed to produce either direct or alternating current. Both direct- and alternating-current generators were developed almost simultaneously.[22]

The first commercially successful dynamo was produced in 1871 by Zénobe-Théophile Gramme, who was born in Belgium but did much of his work in France. It was significantly more efficient than any generator produced previously. Although until the late 1870s it continued to be used primarily by the electrochemical industries, it made the more widespread use of electric lighting inevitable, and by 1879 Gramme had sold over one thousand dynamos. Gramme's dynamo, furthermore, could also function as a motor, a phenomenon demonstrated at the Vienna Universal Exhibition of 1873. In the Philadelphia Centennial Exhibition of 1876, Gramme dynamos powered arc lights, electroplating demonstrations, and other dynamos run as motors.[23]

By the middle of the 1870s, the commercial prospects for electric lighting seemed clear, but the conditions required for an industry of centrally generated electricity required an additional technical advance: how to power multiple lights from a single generator. An inherent problem of an arc light is that the electrodes are consumed as the light burns, which increases the gap between the electrodes until the arc can no longer span it. Some means had to be devised to prevent this. Several "regulators" had been developed initially that adjusted the gap, but putting multiple lamps on the same circuit made these regulators inoperative.[24] This problem was addressed in a novel way by the invention in 1876 of a new type of arc light by the Russian military and telegraph engineer Paul Jablochkoff (Pavel Yablochkov), who worked mostly in Paris.[25] Jablochkoff's "candle" eliminated the need for a regulator by placing the electrodes in parallel with a solid material used as a spacer. The lamps were cheap but short-lived and could not be relit once they were turned off. Jablochkoff was able to install several lamps in series in a single circuit, and he was able to make lamps of varying brightness, although all were too bright for residential use. The connection of arc lights in series became the standard industry practice.[26] Jablochkoff's system, which used alternating current, was installed in numerous locations in Paris both by his Société Générale d'Électricité and by others, and was also used, in 1878 and 1879, in various locations in London.[27] Ultimately, however, Jablochkoff's system was superseded by those using lamps with superior regulating mechanisms, including the successful systems of R. E. B. Crompton in England and both Charles F. Brush and William Wallace-Moses Farmer in the United States.[28] A number of commercial enterprises in various countries began providing arc lighting both to municipal governments for street lighting and to private users, including large stores and factories, in 1879 and 1880. These systems, the first central stations, generally consisted of a number of arc lights connected in series to a generator, controlled by a common switch, which was suitable for street lights and for lights in public places. Residential lighting continued to be provided by gas, oil lamps, or candles.[29]

The problem of the excessive brightness of arc lights was well known, and many inventors tried to tackle this problem, sometimes called "subdividing the light," by developing a fundamentally different form of electric light. If electricity was allowed to flow through an appropriate conductor, the conductor could become hot enough to incandesce. Such an approach to producing light held the promise of permitting a lower-intensity light than that produced by an arc light. A major technical impediment was that the conductor thus heated had a tendency either to melt or to burn up, thereby breaking the circuit. A method had to be found either to increase the life of the incandescing conductor or to automatically replace conductors consumed in the current.

Considerable progress in the development of incandescent lamps had been made in the 1840s and 1850s. Heinrich Goebel, a German who had emigrated to the United States, used incandescent lamps to illuminate a display window in his New York City watch shop in 1854. The Russian Alexander de Lodyguine used two hundred incandescent lamps in 1856 to light up the harbor of St. Petersburg. While Goebel tried to keep his conductor in a vacuum, Lodyguine used a nitrogen-filled bulb.[30] These two methods – vacuum and nitrogen – were pursued by a number of inventors as a means of avoiding oxidation of the conductor. The Englishman Joseph Swan also worked on the incandescent light during this time and determined that carbon was the best conductor. Thirty years later, he returned to his work on the incandescent light and became one of its commercially successful pioneers.[31]

Although numerous inventors had appreciated the problem of protecting the incandescing conductor from the destructive effects of oxygen, they were unable to produce either a complete enough vacuum or a container of inert gas sufficiently devoid of oxygen to enable an incandescent light to have a reasonably long life. This changed in 1865 with the invention of the mercury drop pump by the German chemist Hermann Sprengel. With subsequent improvements, these pumps dramatically improved the ability to produce a vacuum. Swan used a Sprengel pump to demonstrate a workable incandescent light before the Royal Institution in February 1879. Eight months later, Thomas Edison also demonstrated a workable incandescent lamp with a carbon conductor produced with the aid of a Sprengel pump.[32]

While Edison probably should not be remembered as the inventor of the incandescent electric light (for which Swan has an equal claim), he deserves to be remembered as the inventor of the modern electric utility – that is, a system for the production and delivery of electricity.[33] Edison was not a solitary inventor, but rather the head of a multiperson inventing enterprise, and many of the ideas that came from that enterprise may have originated with others.[34] Edison was a successful promoter and had the backing of established financiers willing and able to bring his ideas to market.