The Development of Electrical Power

Networks of Power. Electrification in Western Society, 1880–1930. THOMAS P. HUGHES. Johns Hopkins University Press, Baltimore, 1983. xiv, 474 pp., illus. $38.50.

Electrification is often considered a foundation of modern industrialized society. Until *Networks of Power*, however, the subject has not been explored in a broad-gauge historical study. Happily, the book provides more than a narrative account of men and machines. By looking at a technology as it evolved in response to social, political, and economic circumstances, it avoids explanations based on the internal dynamic of hardware alone. It can be viewed as a model for how Thomas Hughes, a leading scholar of the history of technology, believes others should understand technological change.

The book approaches the subject of electrification by focusing on emerging "systems" in the United States, Great Britain, and Germany in the half century after Thomas Edison created the first successful central power station in 1882. The comparative approach is especially useful for illuminating how cultural environments contributed to patterns of technological evolution. In the United States before World War I, for example, municipal politics usually did not interfere with builders like Samuel Insull, who constructed a large utility in Chicago that took advantage of economies of scale and a wide diversity of customers who used power at different times (thus improving the all-important "load factor"). In Berlin, the political climate also favored the development of large and efficient systems. London utility builders, however, faced the obstacles of a fragmented city government and national legislation that hindered investment in the industry. The resulting system contradicted the principles learned in the United States and Germany and was poorly integrated, having no standards of voltage and frequency. Only after World War I did England finally standardize its system and interconnect facilities with the "Grid" in efforts to catch up with more sophisticated systems in other countries.

In addition to emphasizing systems and nontechnical factors that influenced their development, Hughes employs useful conceptual tools for describing four phases of development in electrification. In the first phase, "inventor-entrepreneurs" dominated by establishing the groundwork for the new systems. Thomas Edison is the hero in this phase as he not only invented light bulbs, generators, meters, and underground cables but also presided over development of the system into a commercial endeavor. Edison is portrayed as a true "systems engineer" in the modern sense, an engineer who examined the entire network of electricity generation, distribution, and usage while always considering how to compete successfully with the gaslight industry. He articulated these concerns even before developing a successful light bulb. In fact, they drove him to invent a bulb that had a high-resistance filament—a move that conflicted with conventional wisdom.

The second phase of electrification is presented as one of "technology transfer." Hughes demonstrates how Edison's power system was altered to meet local conditions of finance, politics, and culture as it moved from New York to London, Berlin, and other cities. The short-distance, direct-current network

Exhibit designed for a health exhibition in Berlin, 1883. In the summer of 1883 German Edison "was looking beyond . . . isolated installations . . . to two central stations in Berlin: one to supply a block of buildings, including the Café Bauer, a well-known Berlin establishment, the lighting of which would attract considerable attention; and another to light central Berlin with fifty thousand incandescent lamps. The latter would function as a model for central stations throughout Germany." By the fall of the year, however, technical and other problems had left the company in "a very sad dilemma," and "the lead in the European lighting business had passed to others." [From *Networks of Power*; courtesy of the National Museum of American History] operated successfully in New York, but, hampered by Parliamentary actions, it transferred poorly to England.

In the third phase, "system growth," electric power companies encountered what Hughes labels "reverse salients"—loci where progress in one part of the system lagged others. Utilities discovered one such salient when trying to extend beyond the small areas served by direct-current stations. After defining the "critical problem" of power transmission losses over large distances—identification of the problem being the first step in eradicating the salient—engineers in the 1890's introduced alternating-current networks. Despite successful demonstration in 1896 with Westinghouse's Niagara-Falls–to–Buffalo line, alternating current did not immediately win the "battle of the currents." The fight lasted several years and resulted more in a compromise, through the use of conversion devices, than in an immediate victory for alternating current.

By the fourth phase, power systems had acquired substantial "momentum." Polyphase alternating current won widespread acceptance, and a "culture" of uniform engineering and business practice grew around it. Critical problems still arose in this phase—an important one was the elimination of transmission losses due to coronal discharges—but they generally fell within the mainstream development and therefore added to momentum. The concept of momentum helps explain events during World War I. Even though war forced power systems to forgo their drive for autonomous growth and profits in exchange for serving national needs, most reverted to prewar behavior after the conflict.

However useful in this case, the concept of momentum presents problems for Hughes's argument that social factors constitute the most important determinants for technological change. After 1900, the managerial goal of improved load factor (which stemmed in large part from the type of technology employed) became universal. Combined with the huge investment of financial and human resources into one alternating-current technology, it created power systems in different countries that looked alike by the 1920's. Large momentum in the power industry implied that the influence of national style diminished after systems emerged in the 1890's.

During the final stage, which took place after World War I, the inventor-entrepreneurs of earlier days lost control of the systems' growth. In their place, financiers and consulting engineers dominated the enterprise by providing the standardization, coordination, and huge capital resources needed for creating interconnected regional networks. In the United States (and to a lesser extent in England), these new managers exploited the holding company, a relatively new institution. Though mired in scandal in the 1930's, holding companies helped the industry achieve technical and economic efficiency.

Hughes's history of electric power ends in 1930, when utility systems had emerged into their recognizable present forms. After 1930, the author argues, the basic structure of electrification remained qualitatively the same despite the intervening depression, governmental influence on regional systems (such as the Tennessee Valley Authority), and world war. Though some readers may miss reading about later events, few new insights about the evolution of power systems would have been gained. The next period for study, I would maintain, begins in the late 1960's, when the electric power industry suffered severe setbacks, raising questions about the values and principles that had served it well for almost a century. Of course, these comments are not meant as criticisms. Instead, they point to a program of further research that has already begun and that will gain clarity as a result of Hughes's excellent study. While some may quibble with Hughes's conceptual tool of "technological momentum," few will fault his emphasis on the social environment that influences technological change. *Networks of Power* is therefore a book that requires serious study by historians and those interested in the reciprocal impact of technology and society.

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The Plant Cytoskeleton

The Cytoskeleton in Plant Growth and Development. CLIVE W. LLOYD, Ed. Academic Press, New York, 1982. xii, 458 pp., illus. $60.

For some years botanical cytologists postulated the existence of a cytoskeleton in plants, but the direct demonstration of cortical microtubules in elongating root tip cells by Ledbetter and Porter in 1963 marks the beginning of investigation of the plant cytoskeleton as we know it today. The progress made during the intervening 20 years is summarized in this book, which integrates studies at the subcellular level with those at the cellular and organ level. Unfortunately, the micrographs, on which the wealth of cytological information on the cytoskeleton is based, are poorly reproduced. Nevertheless, the chapters are well balanced and authoritative, and the book should prove useful to graduate students and to experts, who will appreciate having the subject drawn together in one volume.

The 15 chapters are divided into four sections that consider the molecular components of the cytoskeleton and the role of the cytoskeleton in wall formation, division, and morphogenesis. Introductory chapters provide general accounts of actomyosin (Jackson) and calmodulin (Schleicher *et al.*) in plants, but the central focus of the book is the microtubule, the cytoskeletal component that has received the most attention to date. A broad discussion of microtubule biochemistry (Hyams) emphasizes that we know very little of the properties of tubulin from higher plant cells. Because the protein is highly conserved it may be reasonable to expect considerable similarity between tubulins of animal and plant origin, but the fact that higher plant microtubules are a thousandfold less sensitive to colchicine than animal microtubules leads us to suspect that there may be significant biochemical differences in the constituent tubulins (Hyams).

Though our understanding of the biochemistry of plant microtubules is meager, we have considerably more information about their cytology, especially about their role in the formation of the cell wall. The original observations showed microtubules oriented parallel to the underlying cellulose microfibrils and suggested that microtubules might regulate cellulose orientation. Numerous studies on this topic are critically reviewed by Robinson and Quader, who conclude that microtubules do indeed participate in the control of cellulose microfibril orientation. Observations of and experimentation on wall formation in the alga *Oocystis* (Robinson and Quader) and in stomatal guard cells (Palevitz) provide specific examples of microtubule involvement in cellulose alignment. Since the orientation of the cellulose microfibrils controls the shape of the cell and since the shape in turn influences tissue morphology, it becomes apparent that microtubules are the prime cellular agents regulating morphogenesis. Hardham shows in the formation of a leaf primordium in *Graptopetalum*, in which a change in cellulose microfibril orientation occurs in certain