CERAMICS AND CIVILIZATION

VOLUME

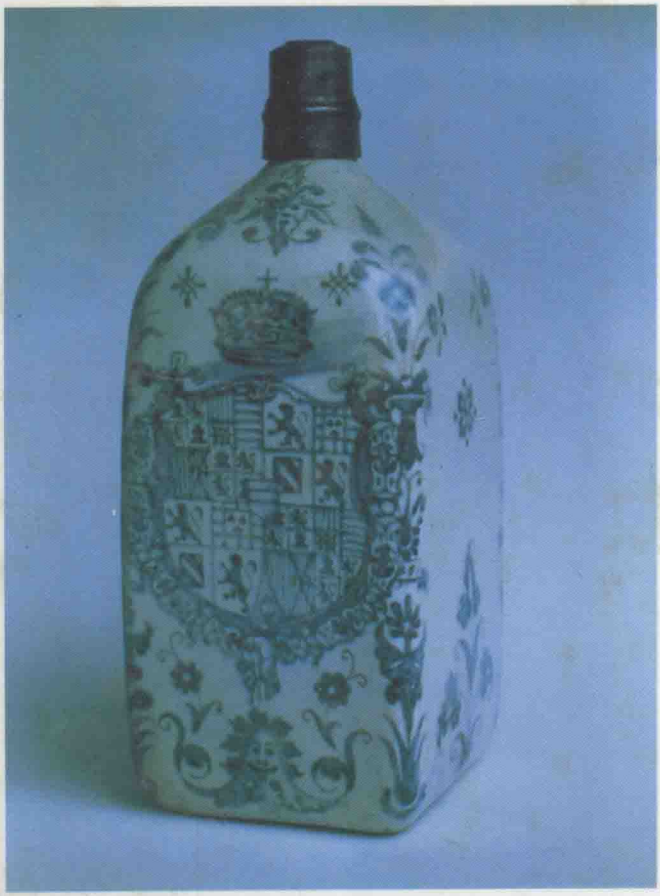
III

High-Technology Ceramics

Past, Present, and Future

The Nature of Innovation and Change in Ceramic Technology

Edited by W. D. Kingery



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HIGH-TECHNOLOGY CERAMICS

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The American Ceramic Society, Inc.
Westerville, OH

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On the cover: This porcelain bottle was made in 1581 under the patronage of Grand Duke Francesco I de Medici and sent as a royal gift to Philip II of Spain. This first European porcelain resulted from a research program of successful high-technology ceramics in the late sixteenth century. (Courtesy of the Musée National de Ceramique, Sévres, France.)

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Volume I. Ancient Technology to Modern Science
Volume II. Technology and Style

Preface

The position of the United States in high-technology ceramics relative to foreign competition, particularly from Japan, which seems to have a lead in innovative ceramics technology, is a matter of national concern. In addition, many large and small organizations are well aware of the anticipated tenfold growth of the high-tech ceramics market by the year 2000. Fulfilling our national interest and ceramic industry objectives requires anticipating and controlling future directions of a highly innovative field. Fortunately, innovation of high-tech ceramics is not all in the future—we have examples from 6000 years ago, Roman times, the nineteenth century, and in the immediate aftermath of World War II. This volume brings together specific case histories, analyses of the driving forces for innovation, cultural and corporate influences, policies of national self-interest, and a historical viewpoint that allow the reader to shape a new understanding of the process of innovation and how it may affect the future of high-technology ceramics.

The book begins with a reminder by Reber and Smith that the history of technology has many facets. While it can be viewed as an expanding system with diffusion between its parts leading to a continuous evolution, it is also a social product and must be seen as the creation of a culture and society. Indeed, its development often influences the nature of culture and society in unexpected ways.

The second section of the book is quite frankly an internalist view of a variety of high-tech ceramic developments in which the influence *of* and influence *on* culture and society are evidenced in many ways. In examples ranging from Egyptian faience discussed by Vandiver and Kingery, ancient refractories discussed by Freestone and Tite, Roman glass discussed by David Grose, Roman concrete and architecture discussed by Lechtman and Hobbs, Chinese celadon discussed by Li Guozhen and Gao Lingxiang, and the development of European porcelain discussed by Kingery, episodes of high-tech ceramic innovations are described from their beginning about 4000 B.C. on up through the eighteenth-century chemical and industrial revolution in Europe which began with the first thoroughly modern government-sponsored ceramic research program. In each case, the social milieu and the role of new ceramics in a larger context is evident.

More recent innovative developments include discussions of modern refractories by Smith and White, of aluminum oxide spark plugs by Morris Berg, silicon carbide by Neil Ault, television phosphors by Mike Notis, nuclear fuels by Joe Burke, silicon nitride and Sialons by Ken Jack, ferroelectrics by Cross and Newnham, and multilayer ceramics by Harold Stetson. Each illustrates in different ways the complexity of interactions of supplier-manufacturer-user, materials and devices, science and technology, and innovative technology as activities in and of society. While common themes are evident, no simple linear analysis seems appropriate to the historical variety.

In the final section we have a perceptive discussion by von Hippel of the sources of innovation based on a continuing research program that will soon be summarized in a book, *The Sources of Innovation* (to be published by Oxford University Press, 1987). He emphasizes that the people who perceive the highest benefits from innovation are the ones who spend the most on it, and that different situations lead to different scenarios. Then Kim Clark, author of the book *Industrial*

Renaissance (New York, Basic Books, 1983), discusses different sorts of innovation, their driving forces, and management, using recent developments in high-technology ceramics as his example. Rustum Roy, author of *Lost at the Frontier* (Philadelphia, ISI Press, 1985), argues that our national policies have been based on much muddled thinking about the nature of science, the nature of technology, and the relationship between them, and that this has inevitably led to mistaken policies. His analysis leads to persuasive and positive proposals as to how technology might best be nurtured. In the final chapter, the way in which the structure of ceramic technology seems to be changing is discussed by Kingery as a necessary (but not sufficient) input for peering into the future.

Overall, the volume clearly disabuses us of any belief that "high-tech" ceramics have sprung up out of nothing in the last decade—rather, they have a long history that can help us prepare for the future. We also are convinced that the history of technology (as evidenced by high-tech ceramics) is intricately interwoven with society and culture and that many of our well-worn stereotypes of the monotonic development of technology and its relationship with science are simply not so. Clearly, new insights are being developed about the sources of innovation and the possibilities of managing high-tech ceramic developments. Alas, it seems that the very structure of ceramic technology and manufacture are changing in ways that will require both a depth of knowledge and a carefully honed intuition for its successful guidance.

In the preparation of this volume the many contributions of Susan Rosevear are gratefully acknowledged. It would have been impossible without the editorial oversight of Esther Lense of the American Ceramic Society and the financial support of the Defense Advanced Research Projects Agency, Materials Sciences Division. Each of the papers has been reviewed, and most have been revised; our heartfelt thanks go out to the anonymous referees who have given much beneficial advice and stimulated improvements.

W. D. Kingery
Editor

Section I

The History of Technology

Contents

SECTION I. THE HISTORY OF TECHNOLOGY

SECTION II. SPECIFIC EXAMPLES OF HIGH-TECHNOLOGY CERAMIC INNOVATIONS

SECTION III. THE NATURE OF INNOVATION AND ITS MANAGEMENT

Contextual Contrasts: Recent Trends in the History of Technology

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The last twenty years have seen the growth and development of an alternative approach to the history of technology: contextualism. John Staudenmaier has defined contextualism as a methodology which combines "design" with "ambience"—contextualist scholars study the technical characteristics and constraints of a particular technology (design) in relation to the economic, social, and political contexts (ambience) in which they emerge and develop. All contextualist historians of technology do not bring the same approach to their studies, however. We identify two basic approaches. The first treats technology as expanding knowledge, the second characterizes technology as a social force or a social product. We review four recent major works in the history of technology which exemplify the contextualist trend. Each of the authors, Thomas Hughes, David Hounshell, David Noble, and Ruth Cowan, occupies a unique position on the spectrum between the two basic approaches to contextualism.

The history of technology is a relatively new field of inquiry. It can be traced, in this country, to the establishment of the Society for the History of Technology (SHOT) in 1958. This does not mean, of course, that the historical study of technology did not exist in America prior to the 1950s. Indeed, from the 1910s through the 1940s a number of individuals became interested in various aspects of technological change and produced important works that now stand as classics in the field. Among the most notable contributors were Louis C. Hunter, Lewis Mumford, Joseph W. Roe, Abbot P. Usher, and Lynn White, Jr.[1] These scholars, as well as others, helped to pioneer the history of technology in America long before it became recognized as a bona fide field of specialization. Owing to their varied backgrounds in economics, engineering, history, and journalism, they tended to work in isolation from one another and lacked any shared notion of professional identity. The founding of SHOT gave continuity to the emerging field and provided its members with a special identity that had not existed before. Due primarily to the efforts of Melvin Kranzberg, the Society's journal, *Technology and Culture,* became an important vehicle of scholarly communication and encouraged research in a variety of new areas.

Impressive scholarly advances have been made in the history of technology during the past twenty-five years. Although attempts have been made throughout this period to report on the direction these advances have taken (and, at times, to suggest new directions), none has been as methodical as the analysis presented in John M. Staudenmaier's

recent book, *Technology's Storytellers* (Cambridge, MA: The MIT Press, 1985). Using the articles published in *Technology and Culture* from the first issue in 1959 through 1980 as his source material, he has studied the language, methodology, and predominant themes of scholarly writing in the history of technology. The result is a valuable historiographic survey which offers significant insights into the development of the field.[2]

Staudenmaier frames his discussion around the related concepts of design and ambience. By *design* he means the purely technical characteristics and constraints of a particular technology under study. *Ambience,* on the other hand, refers to the context (economic, social, political) in which the design emerges and develops. As Staudenmaier points out in an introductory chapter on methodological styles, pre-SHOT histories of technology were dominated by an internalist methodology which addressed questions of design but largely ignored ambience.

Singer, Holmyard, Hall, and Williams' encyclopedic *History of Technology* exemplifies this trend: disciplined attention to technical detail and to changes in design over time, but little or no discussion of the political or cultural contexts in which new technologies developed.[3] SHOT's founders, concerned over the limits of internalism, made a concerted effort during the 1960s and '70s to foster an alternative, contextual approach. The contextualist methodology stresses the importance of both design and ambience, and takes pains to understand their relationship.

Staudenmaier's analysis of *Technology and Culture*'s contents is divided into three chapters, each devoted to a major theme in the history of technology: emerging technology, the relationship between science and technology, and the interaction between technological development and culture. His discussion shows a fairly constant increase in both the number and sophistication of contextual studies in all three areas of discourse since the journal's inception. One effect of the mainstream acceptance of contextualism has been the emergence of a third methodology in the history of technology: externalism. In externalist studies a technology's ambience, not its design characteristics, forms the primary focus of discussion.

The growth and development of contextualism provide the main theme of Staudenmaier's book, and he links it explicitly to the philosophical debate over the ideology of progress:

> The myth of progress poses a particularly vexing problem for historians. Belief in an autonomous progress, beginning in Europe with the "scientific revolution" and proceeding with inevitable necessity in both scientific and technological domains ever since, implies a radical disjunction of method from context and, therefore, of technological design from human culture (p. 164).

In other words, if technological progress is inevitable, then it is independent of context, and contextual issues can therefore have no explanatory power. Staudenmaier finds this "myth" objectionable, and attributes the emergence of contextualism to the myth's growing unacceptability to most historians of technology.

This is not to say that the idea of progress is dead among historians of technology. Staudenmaier devotes his final chapter to the question of

how far beyond "Whig history" (that is, the presentation of technological development as a linear success story) the discipline has progressed. His conclusions are mixed. Although impressed by the extent of contextual discourse among historians of technology, he finds the lack of research in some areas (technological failures, worker and feminist perspectives, non-Western technologies, and critiques of capitalism) to be an indication of methodological imbalance.

Staudenmaier's book is a perceptive, well-organized study that is of considerable use to both established scholars and newcomers to the history of technology. His insistence on the relationship between methodological positions and the ideology of progress, however, is bound to be controversial.

The Contextualist Spectrum

For our purposes, the main strength of Staudenmaier's book is his treatment of contextualism as an important (indeed the most important) methodology available to historians of technology. We will use this discussion as a starting point in our review of some recent major works in the field. In the previous section, *contextualism* was defined as a recognition of the importance of cultural (typically social, political, and economic) factors which affect and are affected by technological development. This definition serves admirably to distinguish contextualism from internalist or externalist methodologies. It could be understood as implying that all scholars who describe themselves as contextualists bring the same approach to their studies. Such is not the case, however (as Staudenmaier himself notes). Indeed, a broad spectrum of approaches to contextualism is evident in the work of historians of technology. The ends of this spectrum correspond to two complementary yet quite distinct interpretations of technological change.

The older and more familiar of these interpretations is that which views technology as a form of expanding knowledge. Here scholarly discourse ranges from narrowly focused "nuts-and-bolts" studies to more complex treatments of innovation as well as the emergence of industrial systems. What distinguishes this approach is its primary emphasis on the evolving technical, managerial, and epistemological features of the subject. According to this perspective, cultural factors have importance chiefly as the background against which the main theme of technical development unfolds. Representative studies are David J. Jeremy's treatment of the transfer of technology in *Transatlantic Industrial Revolution,* David P. Billington's investigations of structural engineering in *The Tower and the Bridge,* Edward W. Constant's analysis of *The Origins of the Turbojet Revolution,* and Edwin T. Layton's research on the historical relations of science and technology as evidenced in "Mirror-Image Twins" and "Scientific Technology, 1845–1900."[4]

The second mode of interpretation concentrates not so much on the creative aspects of technological development as on its social aspects: the reasons for developing a particular technology, the choices made among competing technologies, and the social implications of developing technologies. Here, the cultural context provides the dynamic force of the story, technical factors the background. The idea of technology as a "social force," implicit in this approach, has a rich tradition of scholarship behind it. Probably the best-known work in this area is Lynn White's

seminal *Medieval Technology and Social Change* (see Ref. 1), although one can readily cite other studies such as Daniel R. Headrick's *Tools of Empire,* James J. Flink's *The Car Culture,* and various "retrospective technology assessments" which address the social and political implications of technological innovation.[5] Studies which view technology as a "social product" represent a more recent and controversial aspect of this second approach. Here the emphasis is on the attitudes, ideologies, and values that lie behind technology and, in effect, shape it. Works of this genre treat innovation in the workplace as well as more broadly defined analyses of technological change in local communities, geographic regions, and national cultures. Such an approach is reflected, for instance, in the writings of Edwin Layton, David F. Noble, Merritt Roe Smith, and Anthony F. C. Wallace.[6]

As a means of illustrating the variety of positions available on the contextualist spectrum, we will discuss four major recent works in the history of technology, Thomas P. Hughes' *Networks of Power: Electrification in Western Society, 1880–1930* (Baltimore: Johns Hopkins University Press, 1983), David Hounshell's *From the American System to Mass Production, 1800–1932* (Baltimore: Johns Hopkins University Press, 1984), David F. Noble's *Forces of Production: A Social History of Industrial Automation* (New York: Alfred A. Knopf, 1984), and Ruth Schwartz Cowan's *More Work for Mother: The Ironies of Household Technology from the Open Hearth to the Microwave* (New York: Basic Books, 1983). All four authors acknowledge the importance of studying technology within larger contextual settings. Each, however, occupies a distinctive position on the spectrum of contextualist methodology, hence the title of this paper —"contextual contrasts."

Networks of Power is Thomas P. Hughes' comprehensive study of the development of electrical power systems in the United States and Europe between 1880 and 1930. In the preface to the book, Hughes discusses his approach to the history of technology, placing himself squarely in the contextualist camp:

> I found that . . . with rare exceptions the impact of society, or culture, on the shape of technology had been virtually ignored. Dissatisfied with the internalist's approach, I turned to an exploration of a broad range of factors, events, institutions, men, and women involved in complex networks of power—technical, economic, political, and social (p. x).

Hughes' goal is to explain the development of electrical power systems. For him, the defining characteristic of electrical power technology is the fact that it developed as a system—a network of interconnected components—rather than as a collection of independent inventions. The system concept is crucial to Hughes' argument, and the book is organized around a four-stage model of systems development. The stages are invention and development, technology transfer, system growth, and system momentum. The discussion of invention and development revolves around the work of Thomas Edison. According to Hughes' account, Edison's success in the field of electricity hinged on his systems approach to the problem. Rather than merely inventing the incandescent lamp, Edison realized from the outset that power generators, wiring networks, and light fixtures would all have to be developed before electric

lighting would become a reality. This approach distinguished him from such component inventors as Joseph Swan, the British inventor of the incandescent lamp.

The problems of technology transfer, the second stage of Hughes' model, are illustrated by the attempts to transplant American electrical power technology to England and Germany in the 1880s. Here political and economic forces, which influence the shaping of systems, come into play. The political realities in England, particularly the regulatory impulses of the Gladstone government, resulted in legislation which originally priced electricity out of the lighting market. In Germany, initial conflicts between growing German nationalism and the importation of American technology were smoothed out, and the transfer of technology was successfully effected. Hughes' discussion of the third stage, system growth, likewise relies on a comparative study of power systems, specifically those in Berlin, Chicago, and London. Political and business forces compromised in Berlin, and system growth depended on their continued cooperation. In Chicago, the dominance of Samuel Insull and other manager-entrepreneurs over local political authority resulted in an absence of political limitations on system growth, and a relative increase in the importance of technological and economic limitations. In London, the reverse was true: Political forces placed much sharper restrictions on system growth than technological or economic conditions.

According to Hughes, as a technological system grows, it develops an internal dynamic which makes it difficult for external factors to change the direction of its evolution. This is the fourth stage, that of technological momentum. In the field of electric power, this momentum was due to large amounts of capital investment, the growth of electrical manufacturing firms, the development of electrical engineering education, and the activities of professional engineering societies. (Only a cataclysm like the first World War could change the direction of independent American power companies toward cooperation. But with the end of the war, the industry returned to its previous direction of development.) At this stage the primary obstacles were financial: For example, the development of regional power systems required large-scale capital formation. This critical problem was solved by the emergence of large holding companies, pioneered by financier-entrepreneurs like S. Z. Mitchell.

In *Networks of Power,* Hughes presents a rich and complex study of the development of electrical light and power technology. His findings are convincing and reflect an enormous amount of scholarly research. The nature and presentation of these findings offer some clues to Hughes' underlying methodology.

The theme of the book is the emergence of a dynamic technological system against a background of economic, political, and geographical constraints. Hughes' four-stage model of system development is one of fairly steady linear progress punctuated by temporary obstacles ("reverse salients") both technical and cultural in nature. The narrative focus is on the leading entrepreneurial figures of the electrical power industry, men like Edison, Insull, and Mitchell. The analysis is thus from the top down.

Although Hughes notes that "of the great construction projects of the last century . . . none has been more influential in its social effects . . . than the electrical power system" (p. 1), these effects, and their implica-

tions for consumers of electricity or workers in the electrical industry, are not a part of this study. No reference is made, for example, to linemen or other lower-level employees who played essential roles in constructing and maintaining large electrical power systems. Hughes makes it clear from the outset that the problem under analysis is the development of electrical power technology itself, not labor-management relations or the larger social implications of technological change. The result nonetheless is a fascinating and original work located squarely at the "technology as expanding knowledge" end of the contextual spectrum.

The second book, David Hounshell's *From the American System to Mass Production,* treats the diffusion and assimilation of new technologies among large-scale manufacturers. Specifically, it focuses on how innovations that originated in the antebellum American firearms industry spread to other technically related industries during the nineteenth century and, with further elaborations and additions, eventually culminated with Henry Ford's system of mass production in 1913.

Hounshell's methodological approach has much in common with that of Hughes. Both focus on technical creativity, innovation, and their relationship to the evolution of large industrial systems, and both explicitly reject the idea of unilinear technological progress. Hounshell offers a "diffusion" model, however, to account for the spread of manufacturing innovations among industries as seemingly diverse as sewing machine manufacture and automobile mass production.

In detailing how various innovations filtered from firm to firm and industry to industry, Hounshell breaks new ground. Historians have long realized that a genealogical connection existed between arms making and other metalworking industries in the United States. But they knew relatively little about how it actually took place. Hounshell now makes these connections clear for clock, sewing machine, furniture, reaper, bicycle, and automobile manufacturing, and he does so in exquisite detail. What is more, he reveals how inherently complicated the process of change and adaptation really was. Instead of relating heroic feats of genius, Hounshell chronicles the aggravating, frustrating, and mundane aspects of innovation. In his superb second chapter on sewing machine production, for example, he argues that some manufacturers readily adopted practices from the armories while others did not. As it turns out, the speed with which sewing machine manufacturers availed themselves of the new technology depended on personalities and work traditions within individual firms. Hence the Wheeler and Wilson sewing machine company of Bridgeport, Connecticut rapidly adopted armory practices primarily because its superintendent (W. H. Perry) and several key mechanics originally came from the firearms industry. Indeed, Hounshell notes, "the small Wheeler and Wilson factory seemed a microcosm of Colt's armory" in nearby Hartford (p. 70).

The Singer Manufacturing Company, by far the largest and most famous sewing machine maker, presented a marked contrast to Wheeler and Wilson. Because the firm's owners and overseers were unacquainted with "armory practice," over thirty years elapsed before interchangeable techniques replaced Singer's original labor-intensive "European method" of manufacturing. The same was basically true of one of the leading agricultural machinery manufacturers of the era, the McCormick

reaper works in Chicago. Not until 1880, thirty-two years after its establishment, did the company turn to production methods used in small arms plants, and then only after the firm's founder, Cyrus McCormick, fired his craft-trained brother as shop superintendent and replaced him with a former Colt employee. Whether the subject is sewing machines, agricultural implements, or automobiles, Hounshell is clearly correct when he observes that "the process of diffusion was neither as smooth nor as simple . . . as others would have it" (p. 5).

But that is only part of the story. Even "best practice" firms such as Brown and Sharpe (manufacturers of the Willcox & Gibbs sewing machine), the Pope Manufacturing Company (maker of the Columbia bicycle), and the Ford Motor Company continually experienced difficulties in tooling up for production and maintaining high standards once production was underway. In short, the adoption of new techniques in other industries proceeded, like they had at the armories themselves, by fits and starts. On more than one occasion the Ford Company was beset by design delays and production bottlenecks in its touted mass production system. Indeed, Hounshell describes the changeover from the Model T to the Model A Ford as a chaotic "comedy of errors" (p. 191). The impression one comes away with is how bumpy and twisted the path of technological progress often is.

We began this review of Hounshell's book by comparing it with Hughes' *Networks of Power.* In both works, as indicated, emphasis is placed on technical development, with cultural context providing the background. Hounshell is not content to rest firmly in the "technology as expanding knowledge" camp, however, and makes explicit note of the social implications of his subject. He ends the book with a chapter about the "Ethos of Mass Production" in which he discusses the positions held by various proponents of the new factory system. Indeed, his treatment of such social commentators as businessman Edward Filene, actor Charles Chaplin, and artist Diego Rivera represents one of the most absorbing parts of the book. Yet, as interesting as these sketches are, the reader leaves the chapter with a rather unfulfilled feeling. Perhaps this is so because Hounshell neglects to address the day-to-day social relations of mass production, particularly the worker's response to it. Although he excels at describing the means by which new techniques moved from firm to firm and industry to industry, his analysis stops short of treating what actually happened on the shop floor. Throughout the book he acknowledges that the introduction of mass production techniques "brought serious labor problems" (pp. 11, 182, 307). Yet at no point does he pause to analyze and assess this critical aspect of technological change. As arresting as the art of Chaplin and Rivera is, their work is too artificial and neat to capture the messy human relations of production within factory settings. For all his attention to the social processes of innovation and diffusion, Hounshell's approach, like Hughes', remains essentially an entrepreneurial one.

Not so with David Noble. In his book, *Forces of Production,* the contextual emphasis shifts to the social factors that lie behind technological innovation. Specifically, he attacks two widely held and closely associated beliefs about modern technological development. One is the popular notion, well-known among scholars as technological determin-