The Age of Industrial Laboratories

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The American industrial laboratory had its heyday through the middle decades of the twentieth century. In this era, corporate interests were committed to the value of research and development for the health of industry, and so were willing to invest, sometimes lavishly, in sites where the promise of scientific inquiry could be converted into profitable, patentable discoveries. These laboratories were some of the key sites in which the materials science developed. This chapter will review the history of some of the most important industrial laboratories that nurtured the growth of materials science research in the United States.

Before turning to these individual cases, however, it will be useful to review the origin of the industrial laboratory as a distinct and recognizable site of research, and interrogate the historical circumstances in which they emerged. Materials science, more so than some other fields, owed its character to the institutions that supported it. The industry was one of those institutional settings, and so understanding the industrial laboratory as a site of scientific research in the twentieth century is crucial for situating materials science within the institutional networks that defined its purpose.

The Birth and Character of the American Industrial Laboratory

The origins of the American industrial laboratory were electric. The late nineteenth century saw an explosion of electrical technology and infrastructure, which by the end of the century was consolidated in the hands of three corporations: General Electric (GE), the Westinghouse Electric Corporation, and American Telephone & Telegraph (AT&T). Through the early twentieth century, each would invest in extensive research and development (R&D) operations, driven in part by competition among them, which would establish a powerful template for American industrial research.

The idea that industrial concerns should invest systematically in research in order to improve their market position was not novel. It was in some measure an import of a longstanding German tradition of industrial research, particularly in chemistry.[1] Many of labs that emerged to support the American electric industry nevertheless exhibited distinctive and novel features. As we will see, these features were not universal, but their prevalence did contribute to the success of industrial laboratories through the middle decades of the twentieth century, which is often identified as the golden era of American industrial research.[2]

First, industrial labs were often kept strictly separate from production operations. The function of these laboratories was not to refine exiting industrial processes, but to generate new insights, inventions, and materials, and to uncover new principles, which could potentially expand those operations. Second, credentialed scientists and engineers were hired to staff the laboratories. The growth of American industrial research coincided with the growth of the scientific and technical workforce in the early twentieth century, which created a glut of trained scientists and engineers, attracted by the salaries, practical rewards, and considerable intellectual freedom industrial employment offered. Third, the labs were typically insulated from the pressures of short-term profit. They presumed a stable corporate setting with a long-

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[1] Catherine M. Jackson, "Chemistry as the Defining Science: Discipline and Training in Nineteenth-Century Chemical Laboratories," *Endeavour* 35, no. 2–3 (2011): 55–62.

[2] John Kenly Smith, Jr, "The Scientific Tradition in American Industrial Research," *Technology and Culture* 30, no. 1 (1990): 121–31.

term vision, in which the activities of the labs were expected to inform business operations not just five or ten years out, but decades down the road.[3]

The context these features created favored the development of new materials. The technological infrastructures of 1900 were largely wrought of metal, with a smattering of natural fibers. By the end of the twentieth century, the material world was transformed by new semiconductors, plastics and polymers, and glasses and ceramics, as well as novel metals and alloys. Many of those new materials—as well as new uses for existing materials—sprung from well-staffed, research-oriented laboratories with the freedom to think beyond the constraints of short-term profit. We meet some of those laboratories, and the materials developed within them, below.

General Electric

The General Electric Research Laboratory was established in 1900. General Electric had formed eight years earlier, a merger of the Edison General Electric Company (itself an amalgamation of Thomas Edison's earlier endeavors) and the Thomson-Houston Electric Company.[4] The new research laboratory consolidated the lively research tradition of both its antecedent corporations, under the guidance of Willis R. Whitney, a chemist who GE managed to lure away from the Massachusetts Institute of Technology (MIT).

Other academics would follow. The transition was not always smooth; despite the relative latitude GE offered compared to a job in a production laboratory, the differences between academic and industrial culture was often jarring for those used to a self-directed university life.[5] GE in the early twentieth century was interested in improving incandescent lighting, and new members of the laboratory were hired to direct their energies in that direction.

The efforts paid off in the field of incandescent lighting. William D. Coolidge, who, like Whitney, had begun his research career at MIT, joined GE in 1905. He developed a procedure for producing tungsten filaments, which, when placed in gas-filled bulbs, solved problems previous with incandescent lights, such as gradual blackening of the bulbs, as well as resulting in a product that was both efficient and cheap to produce.[6]

The wealth of trained researchers GE hired, however, meant that its laboratory's focus would not long remain squarely on the problem of incandescent lighting. Another new PhD, Irving Langmuir, would be crucial for expanding the laboratory's scope, particularly into the area of vacuum-tube electronics. Vacuum tubes, and most notably the triode tube patented by Lee de Forest in the United States in 1906, were integral to the emerging field of radio, given their ability to amplify weak electrical signals. By helping GE push forward in vacuum tube research, Langmuir helped GE remain competitive with AT&T, which had secured the patent on de Forest's invention.[7]

By the mid-twentieth century, GE had secured a leading position as a provider of consumer electronics, a position that owed much to its pioneering industrial laboratory. Not

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[3] Leonard S. Reich, *The Making of American Industrial Research: Science and Business at GE and Bell, 1876–1926* (Cambridge: Cambridge University Press, 1985), ch. 1.

[4] W. Bernard Carlson, *Innovation as a Social Process: Elihu Thomson and the Rise of General Electric. 1870–1900* (Cambridge: Cambridge University Press, 1991).

[5] George Wise, "Ionists in Industry: Physical Chemistry at General Electric, 1900–1915," *Isis* 74, no. 1 (1983): 7–21.

[6] Reich, *Making of American Industrial Research* (ref. 3), ch. 4.

[7] David F. Noble, *American by Design: Science, Technology, and the Rise of Corporate Capitalism* (Oxford: Oxford University Press, 1977).

all of the laboratory's efforts bore fruit. Its program aimed to control plant breeding via radiation-induced mutation, for instance, came to naught.[8] But such endeavors are nevertheless indicative of the ethos that animated it: the corporation could be expected to endure, and its long-term health was expected to depend on timely exploitation of the very latest discoveries in science.

Westinghouse

The Westinghouse Electric Corporation was GE's fiercest competitor in its early years. The two companies sparred to gain control over the burgeoning electrical infrastructure, with Westinghouse winning its share of bouts, including the lucrative contract for a hydroelectric dam at Niagara Falls, which it completed in 1895. Westinghouse was to General Electric as George Westinghouse was to Thomas Edison. Whereas Edison was a showman, continually engaged in the assembly of his own myth, Westinghouse was a hard-headed engineer and entrepreneur, less interested in flash and novelty and more invested in the prickly details of technical problems.[9]

This in part explains the subtle differences in research culture at the two corporations. Westinghouse came later to the research laboratory game, opening its lab outside the steel city of Pittsburgh, Pennsylvania in 1916. Established just in time for the entry of the United States into World War I, the Westinghouse Research Laboratory cut its teeth on wartime problems, such as studies relevant to the erosion of gun barrels and other munitions, and analysis of gas-mask materials. Many of its early contributions came in the field of metallurgy, metals being the stuff of the infrastructure Westinghouse sought to build.[10]

After the war, it followed GE in pursuing the radio craze. However, whereas in GE's case, the move to radio represented an expansion of its research mission, in the case of Westinghouse, it represented a narrowing. The laboratory had been founded with a broad vision, rooted in science, in parallel with the mission of GE's research operations. But in the early 1920s, the emphasis shifted to engineering, and to best exploiting technologies that were in the process of maturing, such as radio.[11] These efforts led to notable progress in magnetron research, which would become crucial for radar development during World War II.[12]

The research laboratories at Westinghouse remained insulated from the production arm of the business, but it continued to experience tension between a vision driven by a commitment to basic research and one guided by more practical engineering concerns. The pendulum would swing back toward basic research in the 1930s under the directorship of the engineer Lewis Chubb, as nuclear research caught the eye of the American scientific community. The fascination with the nuclear led Westinghouse to recruit the physicist Edward Uhler Condon, to Pittsburgh, poaching him from an associate professorship at Princeton University.[13]

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[8] Helen Anne Curry, "Industrial Evolution: Mechanical and Biological Innovation at the General Electric Research Laboratory," *Technology and Culture* 54, no. 4 (2013): 746–81.

[9] Steven W. Usselman "From Novelty to Utility: George Westinghouse and the Business of Innovation during the Age of Edison," *The Business History Review* 66, no. 2 (1992): 251–304.

[10] John W. Coltman, "The Westinghouse Research Laboratory—In Memoriam," *IEEE Industry Applications Magazine*, November/December 2004, 9–11.

[11] Thomas C. Lassman, *Edward Condon's Cooperative Vision: Science, Industry, and Innovation in Modern America* (Pittsburgh: University of Pittsburgh Press, 2018), 30–31.

[12] Karl Stephan, "Experts at Play: Magnetron Research at Westinghouse, 1930–1934," *Technology and Culture* 42, no. 4 (2001): 737–49.

[13] Lassman, *Edward Condon* (ref. 11), ch. 3.

Condon's tenure at Westinghouse is emblematic of broader trends in its research laboratory. As a physicist with an academic pedigree but a fascination with practical problems, he arrived in East Pittsburgh with a vision for expanding fundamental research at the laboratory in a way that erased what he saw as an artificial distinction between the pure and the practical. He succeeded to an extent, luring the solid state physicist Frederick Seitz to Westinghouse and convinced the company to support the construction of a new 3 MeV Van de Graaff generator for nuclear research, which it used to exploit an emerging market for radioisotopes—presaging the company's postwar move into nuclear power. But his dreams of attracting a large, highly talented scientific workforce to the laboratory never met his ambitions.[14]

The peripatetic Condon would leave Westinghouse for a government position during World War II, in part a reflection of his frustration with not having been able to bring his vision of a fundamental research laboratory linked to practical concerns to full flowering. Westinghouse thus offers both a comparison and a contrast with GE. Its successes in the materials arena, such as commercializing radioisotopes and alloy development for generators and reactors, was indicative of the advantages offered by a long-term mindset and a trained workforce. But it cleaved more closely to practical concerns, and efforts to push into more speculative areas were often met with skepticism by corporate management.

AT&T

If the American industrial research laboratory can be said to have reached an apotheosis, then it did so in AT&T Bell Laboratories, or Bell Labs. Whereas Westinghouse followed GE's lead but stuck more closely to practical concerns, Bell went the other way, creating a laboratory renowned for the academic-style freedom of inquiry it afforded its researchers. Bell established its laboratory in 1925, and that ethos would bear fruit in 1937, when Clinton Davisson was awarded the Nobel Prize in Physics for work conducted at Bell Labs showing the wave nature of electrons.

Unlike GE and Westinghouse, which were competed directly with each other for control of American electrical infrastructure, AT&T had secured a monopoly over the telephone network. The relevance of Bell Labs to its business mission was therefore not so much to fend of competition as it was to secure its position—that is, to produce developments that would ensure the reliability of the telephone network, and to anticipate major scientific or technological changes that might destabilize AT&T's monopolistic position. Bell therefore had a distinct incentive to invest in basic research. Its position in the marketplace was secure, its investment in basic research served in some ways to keep government regulators at bay, and the potential threats and opportunities scientific research represented were mostly long-term.

These features help account for why it was Bell Labs that hosted the invention of the transistor in 1947. Bell had been an early adopter of quantum theory, developing an expertise in the field at a time when most American universities still lacked a quantum theorist.[15] By the 1940s, it boasted one of the most impressive collections of solid state physicists in the world. Stefan Machlup, who held a postdoc at Bell after World War II, wrote to William Shockley, the co-director of the Bell solid state division and co-inventor of the transistor, "I think everybody on my hall was doing exactly what he wanted to do," and marveled at the fact that

[14] Lassman, *Edward Condon* (ref. 11), ch. 4.

[15] Lillian Hoddeson, "The Entry of the Quantum Theory of Solids into the Bell Telephone Laboratories, 1925–40: A Case-Study of the Industrial Application of Fundamental Science," *Minerva* 18, no. 3 (1980): 422–47.

"if you've got an obscure technical problem, chances are that somewhere in the two-mile network of corridors sits *the* expert on this particular specialty."[16]

The transistor became possible because of some very abstract developments in the understanding of the electrical properties of solids, in particular semiconductors. By preparing "doped" samples of silicon, germanium, or another semiconducting material, in which a pure crystal has some impurities introduced to it in the form of another element, it is possible to create materials with extra electrons or "holes" (places where electrons would otherwise be, which behave like particles inside solids) that can be more easily moved into the substance's conduction band. Exploiting these properties makes it possible to create a device that mimics the behavior of a triode tube: in particular, amplifying and rectifying electrical currents, and acting as a switch.[17]

Such a device had obvious advantages for a company responsible for a national network built with vacuum tubes, which were large, slow to warm up, and subject to breakage. But nor was it an exercise in simple gadgeteering—it rested on cutting-edge theoretical understanding, as provided by the likes of John Bardeen, who would go on to become the only individual to win two Nobel Prizes in physics, following his role in developing the BCS theory of superconductivity.[18]

Bell Labs would remain the epicenter of American solid state physics research, both basic and applied, for decades, before AT&T's monopoly was broken by the US federal government in 1984. It made many of the key strides in semiconductor physics, as well as in studies of magnetic and amorphous materials, with an intellectual output (at least as measured by papers in top journals) that rivalled or surpassed the top university physics departments.[19] It was in some sense sui generis, the protection AT&T's monopoly afforded meaning it could take risks that would deter other corporations, but in another sense, it embodied the commitment to long-term risk taking that drove materials development in industrial contexts through the middle of the twentieth century.

Eastman Kodak

The laboratories we have considered thus far were all established to support the operations of industries managing large-scale infrastructures. The Kodak Research Laboratories, in contrast, founded in 1912, focused instead on smaller scales. As a photography company, its interests were mostly chemical, and patents were its bread and butter. In the early twentieth century, this meant patents on the products and processes involved in both commercial and consumer technologies, but later in the twentieth century, the laboratories at Eastman Kodak found other opportunities for the chemical expertise they contained. Their influence was particularly strong in the field of semiconductor manufacture.

The laboratory grew rapidly under the guidance of its first director, the British the photochemist C. E. Kenneth Mees. From a staff of just 20 shortly after its opening, the laboratory's workforce grew to 1,175 by 1955, occupying a laboratory of nearly 300,000 square

[16] Stefan Machlup, letter to William Shockley, May 30, 1955, William Shockley Papers, University of Illinois Archives, box 2, folder Correspondence 1954 and 1955.
[17] Lillian Hartmann Hoddeson, "The Roots of Solid-State Research at Bell Labs," *Physics Today* 30, no. 3 (1977): 23–30.
[18] Lillian Hoddeson and Vicki Daitch, *True Genius: The Life and Science of John Bardeen: The Only Winner of Two Nobel Prizes in Physics* (Washington, DC: Joseph Henry Press, 2002).
[19] Joseph D. Martin, *Solid State Insurrection: How the Science of Substance Made American Physics Matter* (Pittsburgh: University of Pittsburgh Press, 2018), 142–43.

feet.[20] It naturally focused on photo emulsions, with the goal of improving commercial photographic processes. Because it pursued a patent-driven strategy, Kodak valued secretly, drawing what researchers referred to as a "silver curtain" between different departments of the research and production operations.[21]

Mees, however, was convinced that successful development could not be programmed, and encouraged a culture of free enquiry at the laboratory. He was convinced that the function of an industrial laboratory was to encourage researchers, who might, if left to their own devices, choose to focus on narrowly practical aims, to engage with fundamental questions, publish in the open scientific literature, and generally keep abreast of the latest developments in their fields of specialty.[22] Kodak therefore represents yet another mode of industrial research in mid-twentieth century America. It put considerably more emphasis on secrecy, even internally, than many other major laboratories, but it nevertheless maintained a strong emphasis on fundamental research and contributions to science at large, which it regarded as a wellspring of its most lucrative product—patents.

Kodak's strategy of pursuing chemical patents brought them new relevance during the semiconductor boom, when finding new resist materials for the lithographic processes used to manufacture integrated circuits became a pressing priority.[23] As pressure mounted to maintain the progress of Moore's Law—the phenomenon of the regular doubling of transistor density on microchips—that pressure manifested in a demand for better machines and processes for semiconductor manufacture.[24] Kodak filed a patent one of the first photoresists, KPR, in 1951.[25] It would go on to become a crucial developer of new resist materials, its industrial laboratory thus dedicating itself both to generating new materials, and to reconfiguring the processes used to manufacture other materials.

DuPont

Patents were among the most coveted spoils of World War I. Germany, through the nineteenth century, had developed a world-leading chemical industry. Following the cessation of hostilities, the Woodrow Wilson administration established the Chemical Foundation, Inc., which seized German chemical patents, with the mission to sell or assign them to American corporations. The corporation that benefited the most from these seizures is one that would become synonymous with the American industry over the coming decades—DuPont.[26]

In the wake of this windfall, DuPont established its fundamental research program. It launched in 1927 and it was inspired by General Electric, and by the German chemical industry from whose patents it now benefitted. Charles M. A. Stein, the program's director, was convinced that the program would benefit the firm's public relations, increase morale and productivity among its technical workforce, and lead to potentially commercializable

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[20] Nicolas Le Guern, *Contribution of the European Kodak Research Laboratories to Innovation Strategy at Eastman Kodak* (PhD dissertation, De Montfort University, 2017), 120.

[21] Le Guern, *Contributions* (ref. 20), 15.

[22] Steven Shapin, *The Scientific Life: A Moral History of a Late Modern Vocation* (Chicago: University of Chicago Press, 2008), 138–39, 151.

[23] Joseph D. Martin and Cyrus C. M. Mody, "Lithography," in *Between Making and Knowing: Tools in the History of Materials Research*, ed. Joseph D. Martin and Cyrus C. M. Mody, 327–40 (Singapore: World Scientific, 2020).

[24] Cyrus C. M. Mody, *The Long Arm of Moore's Law: Microelectronics and American Soceity* (Cambridge, MA: MIT Press, 2017).

[25] Louis M. Minsk, Werter P. Van Deusen, and Earl M. Robertson, Photosensitization of polymeric cinnamic acid esters, US Patent 2,670,287A, filed January 1, 1951, issued February 23, 1954

[26] Kathryn Steen, "Patents, Patriotism, and 'Skilled in the Art': USA v. The Chemical Foundation, Inc., 1923–1926," Isis 92, no. 1 (2001): 91–122.

discoveries. Among the scientists Stein was able to attract with this scheme was Wallace H. Carothers, a theoretical organic chemist who joined DuPont with the promise that he would not be compelled to undertake practical work.[27]

In an emblematic example of the way the fundamental and the practical tended to bleed into one another in industrial contexts, Carothers's curiosity-driven work on synthetic organic compounds soon lead to one of the most iconic material innovations of the twentieth century: nylon. Carothers was interested in the general processes leading to polymerization, but in an era when the microworld constituted a new frontier of investigation, opened up by new instruments and techniques, the quest to understand polymers quickly led to the generation of new polymers for which practical uses could be readily found.[28] Carothers's team synthesized neoprene in 1930, and by the mid-1930s was in the process of perfecting what would become nylon, which would go on to have an astoundingly successful commercial life.

The creation of nylon is in many ways indicative of some of the most productive habits of industrial research that emerged in interwar America. It grew from fundamental research, though crucially fundamental research undertaken in a context where the possibility of eventual applications, however distant, was never far from the mind.[29] It also involved the coordination of different types of expertise—theoretical chemistry, to be sure, but also expertise in high-pressure apparatus, the chemistry of ammonia, and the knowledge of production process. The invention and production of nylon pioneered a process that would becoming the foundation of the discipline of chemical engineering.[30]

IBM

The opening of the microworld that permitted DuPont's polymer research program to thrive also laid the foundations for a new type of industrial laboratory in the postwar period, one dedicated not to emulsions, polymers, and chemical processes, but to solids, surfaces, and electrical processes. That is, industrial laboratories with an interest in materials sprung up around the computer industry. Indicative of this trend is IBM, which invested heavily in commercializing semiconductors and parlayed that expertise into dominance of the computer industry through the 1960s and 1970s.

Although IBM was representative of a mid-century shift toward an emphasis on computing in American industrial laboratories, it was unusual in other respects. Not for nothing did IBM come to be known as "Big Blue." In the decades after World War II, it blossomed into a massive, multi-national corporation. Its research infrastructure followed suit. Its first laboratory, the Watson Scientific Computing Laboratory, was established at Columbia University in 1945. Just over a decade later, IBM launched its Zurich Research Laboratory in Switzerland. It would move to its Yorktown Heights, NY, headquarters in 1961, and before the end of the century would establish branches established in Haifa, Israel (1972), Toyko, Japan (1982), Almaden, Spain (1985), Beijing, China (1995), and New Delhi, India (1998).[31] This expansion made IBM the world's most expansive industrial research operation, and although it

[27] John K. Smith and David A. Hounshell, "Wallace H. Carothers and Fundamental Research at Du Pont Science," *Science*, New Series 229, no. 4712 (1985): 436–42.
[28] Augustin Cerveaux, "Taming the Microworld: DuPont and the Interwar Rise of Fundamental Industrial Research," *Technology and Culture* 54, no. 2 (2013): 262–88.
[29] Cerveaux, "Taming the Microworld" (ref. 28).
[30] Pap A. Ndiaye, *Nylon and Bombs: DuPont and the March of Modern America* (Baltimore: Johns Hopkins University Press, 2007).
[31] More recently, IBM has also opened research operations in Brazil, Ireland, Australia, Kenya, and South Africa.

was unusual for its size, it was representative of the increasingly international character of industrial research during this period.

Both the size and distributed nature of IBM research were conducive to fundamental research with an applied sensibility of the type that had become the hallmark of American industry by the post–World War II era. IBMs labs were well-resourced, and researchers at IBM's satellite facilities often felt as though no one was watching them too closely. In the 1980s, IBM's Zurich lab would be recognized by two Nobel Prizes in Physics. In 1986 Gerd Binnig and Heinrich Rohrer were recognized for their work on scanning–tunneling electron microscopy. The following year, J. Georg Bednorz and K. Alexander Müller would win for their discovery of high-temperature superconductivity. When asked what accounted for such a small, out-of-the-way lab achieving such success, one IBM executive reportedly replied, "poor management."[32]

The scanning tunneling microscope would become particularly successful for IBM. This was not, all kidding aside, on account of poor management, but because IBM had the operations in place to quickly fine-tune and produce the instrument, in an off-the-shelf, black-boxed form that could be marketed to other laboratories.[33] This was the case with many of IBM's developments. Like Kodak, it was involved in the production of resist materials. It developed the first electron-beam resist material in 1967 and was positioned to deploy it in the developing field of electron-beam lithography in the 1970s and 1980s.[34]

Although unusually large and distinctively distributed, IBM nevertheless indicates how the ethos of American industrial research forged in the early twentieth century carried over into the late-twentieth century. It focused on emerging scientific fields that were ripe for exploitation, empowered its researchers to explore those areas without much top-down guidance of their research programs, and remained ready to pounce on commercializable discoveries—though by the 1950s and 1960s, those growth areas were dominated by semiconductors and the tools used to manipulate and manufacture them.

<u>RCA</u>

In 1941 the Radio Corporation of America (RCA) began to centralize its research operations. Like AT&T, RCA was a company that made the transition from vacuum tubes to transistors. But like IBM, its concerted focus on in-house research was largely an outcropping of the mid-century. RCA is also a useful contrast point to the other laboratories considered because its management was more circumspect about the operational value of basic research.

Especially in the 1950s departed from the model pioneered by GE and Bell and maintained connections between its research and production operations.[35] Once the transistor was invented, its commercializable potential was widely evident, but the problem of manufacturing semiconductors at scale was notoriously difficult. Silicon or germanium crystals had to be grown to the right purity with just the right distribution of dopants. Contacts between components had to be precise. Even small faults in the materials production or assembly process could result in costly production failures.[36] The links RCA maintained

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[32] Cyrus C. M. Mody, *Instrumental Community: Probe Microscopy and the Path to Nanotechnology* (Cambridge, MA: MIT Press, 2011), 49.

[33] Mody, *Instrumental Community* (ref. 32).

[34] Martin and Mody, "Lithography" (ref. 23).

[35] Hyungsub Choi, "The Boundaries of Industrial Research: Making Transistors at RCA, 1948–1960," *Technology and Culture* 48, no. 4 (2007): 758–82.

[36] Stuart W. Leslie, "Blue Collar Science: Bringing the Transistor to Life in the Lehigh Valley," *Historical Studies in the Physical and Biological Sciences Historical* 32, no. 1 (2001): 71–113.

between its research and production operations made them more adept at overcoming such challenges.

RCA would restructure its operations in the late 1950s, adopting a format more in line with its competitors, with production and research held at arm's length.[37] Its president, David Sarnoff, held fundamental research in high regard and sought to strike a balance between the two in RCA's Princeton laboratory, the David Sarnoff Research Center, named in his honor.[38] RCA's career as a semiconductor company, though, would be indicative of its operations in the early 1950s. It excelled as a producer but lagged when it came to the sort of laboratory research that regularly generated new developments in semiconductor materials through the 1960s and 1970s.

Curiously, the balance between research and production would be reversed in the case of RCA's development of the liquid crystal display (LCD) in the 1960s and 1970s. RCA had been a wildly successful color television pioneer, and it aimed to follow up that success. The principles behind the LCD involve the sort of productive overlap that industrial laboratories were built for. It involved developing new materials that could exist in liquid crystal phase, and taking advantage of their responses to electric and magnetic fields to manipulate their optical properties. The ingenious combination of chemical synthesis with knowledge of the mechanical, electromagnetic, and optical properties of molecules made flat-screen displays possible.[39]

But RCA, content with the smattering of patents to flow from this research, failed to effectively commercialize it. An ill-fated move into the computer manufacturing sector made RCA management more risk averse, and it's support for the ambitious LCD program waned. After selling off the relevant patents, RCA withdrew from LCD development, leaving it to be commercialized by other firms, mostly in Japan.[40] In 1985, RCA would be acquired by General Electric, and the Sarnoff Labs were phased into a contract research facility.

Conclusion

"This is the most remarkable company I have ever run across," the University of Chicago chemist Thorfin Hogness wrote in 1948. "Originally it started as a manufacturer of sandpaper. Then it branched out into products which require coatings. As a result of this, they invented scotch tape, which put the company on the map." Hogness went on to list a number of other recent accomplishments of the Minnesota Mining and Manufacturing Company, better known as 3M, and concluded that "the relationship between management and employees in this company must be very good."[41] Chicago was targeting 3M as a patron for its new, industry-funded Institutes for Basic Research—among them the Institute for the Study of Metals. Although Chicago did not manage to enlist 3M funding, they remained impressed with its operations and appreciative of what they saw as the company's high regard for basic research.[42]

[37] Choi, "Boundaries" (ref. 35).

[38] Benjamin Gross, "The Quest for "Magnalux": Redefining Technological Success and Failure at RCA, 1951–1956," *Bulletin of Science, Technology & Society* 31, no. 6 (2011): 435–47.

[39] Benjamin Gross, *The TVs of Tomorrow: How RCA's Flat-Screen Dreams Led to the First LCDs* (Chicago: University of Chicago Press, 2018).

[40] Benjamin Gross, "How RCA Lost the LCD," *IEEE Spectrum* 49, no. 11 (2012): 46–52.

[41] Thorfin Hogness, confidential report of an interview with W. L, McKnight, R. P. Carlton, C. W. Walton, and Nelson Taylor, Minnesota Mining and Manufacturing Company, May 7, 1948, University of Chicago. Division of Physical Sciences Records, University of Chicago Special Collections, Chicago, IL, Box 8, Folder 15.

[42] Joseph D. Martin, "The Simple and Courageous Course: Industrial Patronage of Basic Research at the University of Chicago, 1945–1951," *Isis* 111, no. 4 (2020): 697–716.

This anecdote is useful because it highlights some of the limitations of the approach this chapter has taken thus far. It has highlighting aspects of the histories of a few prominent industrial laboratories, but many smaller corporations also supported materials research; some of the most crucial instruments for materials science, for instance, were developed and commercialized in small companies, often those that spun off of academic research projects. Materials research occurred within companies that did not invest heavily in "fundamental" research, but still regarded their work into using existing materials to generate new products as "basic research." And collaborations between industry and academia—as well as industry and government—was crucial for the development of American industrial research, particularly around material, which were often developed in academic settings and deployed in military settings.

Focusing on a few remarkable institutions nevertheless allows both patterns, and the notable exceptions to them, to emerge. First, the American industrial research laboratory was a potent incubator of new materials, as well as the discipline of materials research. Many polymers, semiconducting materials, plastics, emulsions, and other useful assemblages of matter were first synthesized in American industrial labs, and these labs in turn gave a home to a growing cadre of researchers who began to self-identify as materials scientists.[43]

Second, the distinction between basic (or pure, or fundamental) and applied research, advanced for political purposes in various eras,[44] quickly collapsed into incoherence within the confines of an industrial laboratory. Different sites differed in the degree of managerial oversight, and the latitude researchers felt to push into areas tangential to the business mission of the corporation, but they were similar insofar as they regarded "basic" or "pure" or "fundamental" as part of their mission, and nurturing that research as a potential wellspring of new technologies, which often meant new materials and new uses for them.

Finally, whatever similarities make it sensible to treat the twentieth-century American industrial laboratory as a distinct historical phenomenon—such as the features discussed in the introduction—these institutions themselves exhibited remarkable diversity. GE provided an influential exemplar, but other successful industrial research operations used different relationships between research and production, gave researchers different degrees of latitude, and employed scientists with different ranges of expertise. The mid-twentieth century might indeed have been a golden age of industrial research, but that does not mean that "industrial research" meant the same thing to every lab conducting it. These labs were a diverse as the materials that they produced, the variety of which is a large part of why we label this age a golden age.

Biographical Note
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[43] Bernadette Bensaude-Vincent, "The Construction of a Discipline: Materials Science in the United States," *Historical Studies in the Physical and Biological Sciences* 32, no. 2 (2001): 223–48.
[44] Mario Daniels and John Krige, "Beyond the Reach of Regulation? 'Basic' and 'Applied' Research in the Early Cold War America," *Technology and Culture* 59, no. 2 (2018): 226–50.