Appendix II – A Brief History of U.S. Innovation in Chemistry

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The financial contributions of chemistry as a discipline can be seen in the local and regional economies of Western Europe as early as 1746 (Britain, Roebuck's lead chamber process for alkali); however, significant and systematic contributions were not seen until the 1860s with the rise of organic chemistry in Germany. Advances in chemistry prior to that time were mainly serendipitous in nature and highly localized. They usually depended strongly upon the expertise of one person and focused on a single product or product line. Broader commercialization of chemistry required advances in management and coordination of efforts within academic and industrial organizations. Additionally, a juxtaposition of academic and industrial organizations who shared a common focus on research and development was needed.

Although Antoine Lavoisier first established chemistry as a science in eighteenth century France, it was Justus von Liebig in Germany who was credited with first forming teams of researchers working under the common direction of an established professor. These research teams also became closely aligned with large, multiproduct companies with significantly deep pockets to sustain long term research and development efforts. Similar alliances soon followed in Switzerland (Ciba, Geigy, and Sandoz), the United Kingdom (ICI) and the United States (DuPont, and Monsanto) in the 1910s and 20s. Mergers of smaller chemical companies in the U.S. also resulted in the formation of Dow, Union Carbide, and Allied among others.[1]

During the 1920s, the most financially successful U.S. chemical companies began to institutionalize innovation through systematic in-house research and development programs. In parallel with advances in science and engineering at U.S. academic institutions and with the support of the government, these companies became industrial powerhouses for economic development. In the period following WW II, the U.S. economy saw unprecedented growth.

Chemistry in the U.S. has been unparalleled in the creation of new science and engineering jobs in the U.S. Between 1889 and 1946, the chemicals, glass, rubber and petroleum industries accounted for nearly 40 percent of the number of laboratories founded in the U.S. Additionally, the chemicals, rubber, and petroleum industries accounted for slightly more than 40 percent of total research scientists and engineers in manufacturing spanning the period from 1921 to 1946. Table II-1 below provides research laboratory employment data for the chemical, petroleum, and rubber industries in selected years between 1921 and 1946 (over nineteen manufacturing industries and in manufacturing, excluding miscellaneous manufacturing industries were included in the TOTAL – All industries figures) as tabulated by Mowrey from the National Research Council surveys of industrial research employment. [2]

[1] Achilladelis, B.; Antonakis, N. The Dynamics of Technological Innovation: The Case of the Chemical Industry *Research Policy* **2001,** 30, 1-34.
[2] Mowery, D. C.; Rosenberg, N. *Paths of Innovation: Technological Change in 20th Century America*; Cambridge University Press: New York, 1998.

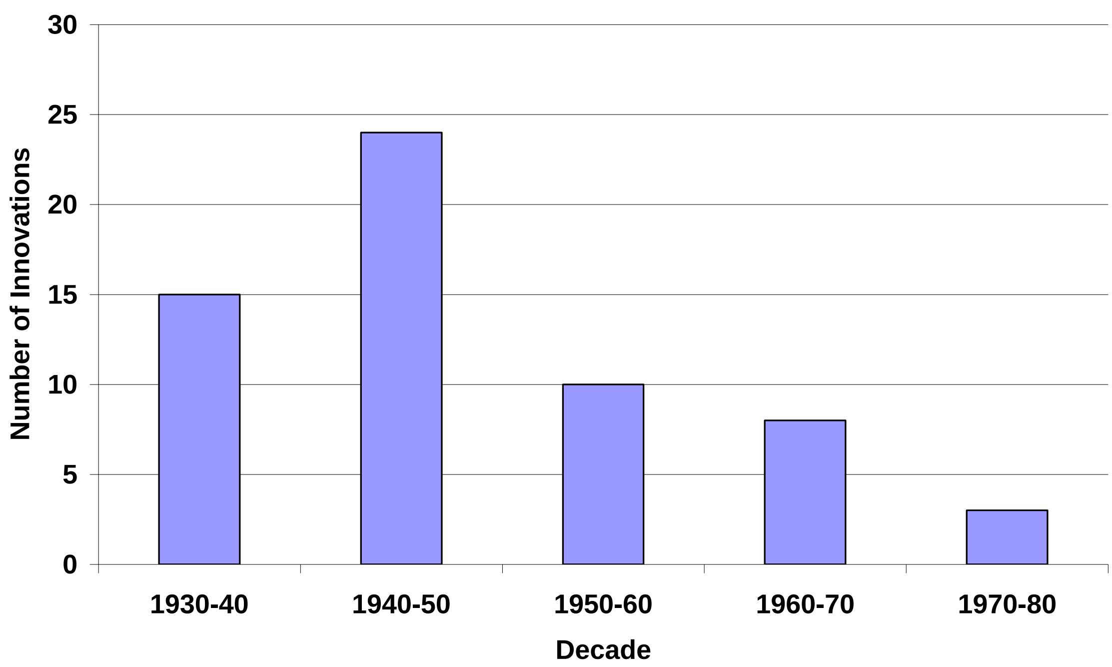
Table II-1. Employment of Scientists and Engineers in Industrial Research Laboratories in U.S. Manufacturing Firms, 1921-46

	Number Employed (Employed per 1000 Production Workers)				
Industry	**1921**	**1927**	**1933**	**1940**	**1946**
Chemicals	1,102 (5.2)	1,812 (6.52)	3,255 (12.81)	7,675 (27.81)	14,066 (30.31)
Petroleum	159 (1.83)	465 (4.65)	994 (11.04)	2,849 (26.38)	4,750 (28.79)
Rubber Products	207 (2.04)	361 (2.56)	564 (5.65)	1,000 (8.35)	1,069 (5.2)
TOTAL – All Industries	2,775	6,274	10,918	22,777	45,941

Source: Mowery, D. C.; Rosenberg, N. *Paths of Innovation: Technological Change in 20th Century America;* Cambridge University Press: New York, 1998.

From 1950 to 1974, chemical production expanded at a rate roughly twice that of the gross national product. From 1930 to the early 1980's, there were 63 major (or disruptive) innovations in chemical products. In addition to major developments in plastics and fibers, scientists invented fiberglass, silicones, herbicides, epoxides, flame retardants, high-nitrogen fertilizers, and automotive catalytic converters (Figure II-1).[3]

Figure II-1. Number of Innovations per Decade, 1930-1980



[3] Bennett, M. J.; Kline, C. H. Chemical: An Industry Sheds Its Smokestack Image. *Technology Review* **1987,** July *Issue*, 36-45.

The peak decade for disruptive chemical innovation in the U.S. was the 1960's, when eleven major new processes were introduced, including Amoco's process for terephthalate and Standard Oil's process for acrylonitrile—both key intermediates for fibers. [4]

In a study by economists Martin Neil Baily and Alok K. Chakrabarti of the Brookings Institute, it was noted that growth of the chemical industry continued rapidly until 1973, when growth slowed substantially. Figures for the multifactor productivity growth in U.S. chemistry (excluding pharmaceuticals) can be seen in Table II-2.

Table II-2. Multifactor Productivity Growth[a] in the U.S. Chemical Industry, 1965-83

Percent Per Year	1965-73	1973-79	1979-83
Unadjusted	3.09	1.73	0.98
Adjusted[b]	3.10	1.91	2.53

Source: Bailey, M. N.; Chakrabarti, A. K. *Innovation and the Productivity Crisis*; The Brookings Institution: Washington, DC, 1988.

a. *Multifactor productivity growth is calculated as the rate of growth of GDP originating in each industry minus the weighted average of the growth rates of the capital and labor inputs.*
b. *The adjustment of growth rates are calculated by multiplying the capital input by the Federal Reserve Board's industry-specific measure of capacity utilization.*

Marked and similar declines in innovation are also observed for the U.S. chemical industry after 1973. The decline is most noticeable in the area of chemical product innovations.

Table II-3. Innovations in the U.S. Chemical Industry, 1967-82
Average number per year

Period	Chemical Products	Chemical Process	Equipment	Instruments
1967-73	332.0	39.0	107.9	29.6
1974-79	38.8	32.3	56.7	18.2
1980-82	64.7	34.7	104.7	54.0

Source: Bailey, M. N.; Chakrabarti, A. K. *Innovation and the Productivity Crisis*; The Brookings Institution: Washington, DC, 1988.

Baily and Chakrabarti further classified innovations into three categories: Radical or Major Importance, Significant Improvement, and Minor Importance. The results of their analysis are presented in Table II-4. It should be noted that for the purposes of this paper the category of Radical or Major Importance most closely corresponds to Disruptive Innovations as defined in the introduction of this report. As would be expected, few of the innovations between 1967 and 1982 were classified as Radical or Major Importance. The majority were improvements to existing products or product lines; and therefore, were categorized as either Significant Improvement, or Minor Importance. However, substantial decreases in the number of innovations can be observed in all but the Minor Importance category.

[4] Bennett, M. J.; Kline, C. H. Chemical: An Industry Sheds Its Smokestack Image. *Technology Review* **1987,** July *Issue*, 36-45.

Table II-4. Product Innovations in the U.S. Chemical Industry, by Technical Importance, 1967-82
Average number per year

Period	Radical or Major Importance	Significant Improvement	Minor Importance
1967-73	2.4	96.9	232.6
1974-79	0.2	9.0	29.7
1980-82	0.0	5.7	59.0

Source: Bailey, M. N.; Chakrabarti, A. K. *Innovation and the Productivity Crisis*; The Brookings Institution: Washington, DC, 1988.

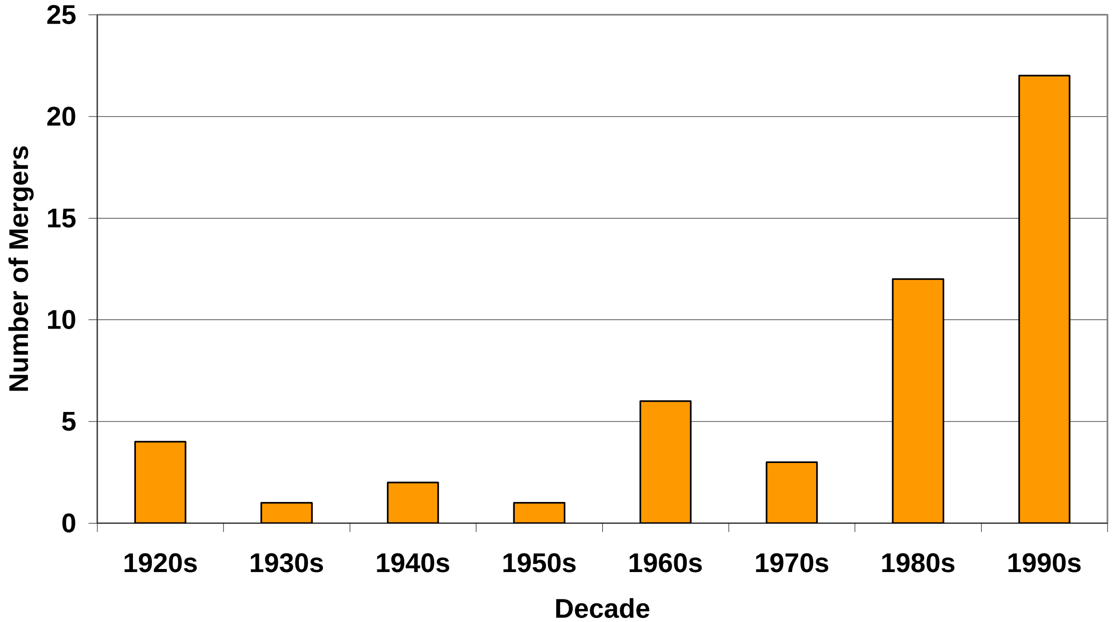
Bennett and Kline observed that the decline in innovations during the early 70's corresponded with the maximum demand for synthetic fibers and their derivatives. Consumer preferences shifted to natural and modified natural fibers. With a lack of innovation, chemical companies entered a competition to produce the same materials less expensively than their competitors. Capacity grew to levels exceeding consumer demands, products were commoditized, and global competition with companies in countries with cheaper feed stocks took their tolls on U.S. chemical industry profits. Philosophical changes began to take place in the way that chemical companies were run, and a higher emphasis was placed on producing products that customers knew and wanted rather than finding markets for new or existing products.

Between 1975 and 1979, U.S. chemical companies cut R&D spending from 2.8 percent of profits to 2.5 percent as a means of cutting operating costs. They also sold or spun off unprofitable subunits, and U.S. companies pulled out of foreign markets where they were unable to compete.

The 1980's were tumultuous for chemical manufacturers with wild swings in oil prices, fluctuations in exchange rates, new environmental regulations, and in 1982 and 1983—the most severe recession faced by the chemical industry in over 50 years. Companies did what they could to survive. Workforce reductions in R&D, planning and marketing research became common. [5] Corporate raiders also invaded less profitable companies during the 80's selling off their constituent subunits piecemeal. Examples of companies that were divested include GAF, NL Industries, and Uniroyal. The 80's also saw an increase in the number of mergers and acquisitions (M&A) in chemistry. In prior decades, M&A activity was limited to single digits. The ramp up in the number of M&A's continued throughout the 90's and 00's with concomitant reductions in force and greater decreases in the percentage of profits invested in R&D.[6]

[5] Bennett, M. J.; Kline, C. H. Chemical: An Industry Sheds Its Smokestack Image. *Technology Review* **1987,** July *Issue*, 36-45.
[6] *R&D Meets M&A*; Daemmrich, A. A., Ed.; Chemical Heritage Foundation: Philadelphia, 2004.

Figure II-2. Mergers in Chemical, Agrofood, and Pharmaceutical Companies by Decade, 1920s-1990s



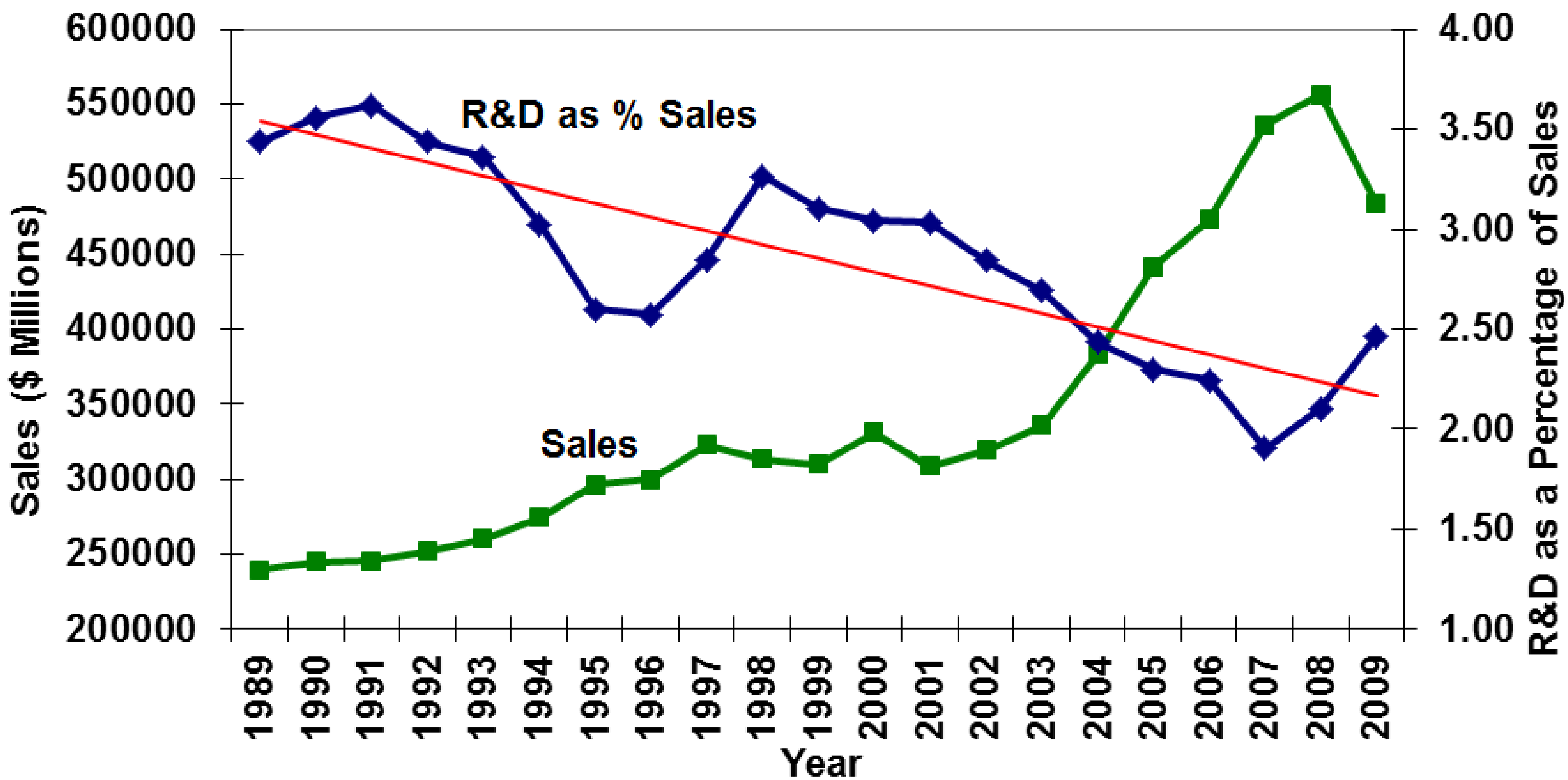
Source: Lodorfos, G.; Walsh, V. Innovations in Chemicals and Related Products. *Technology Analysis & Strategic Management* **2002,** *14.*

Driven by market pressures to meet earnings targets, chemical companies steadily decreased R&D expenses as a percentage of sales throughout the 1990's and 2000's. Minor exceptions to this trend can be observed in 1997-8, and 2008-9; however, the overall pattern is dramatic with the percentage decreasing from just under 4.0 % in 1990 to 2.5 % at the end of the millennium (see Figure II-3). These decreases in R&D spending correlate strongly with decreases in innovation, especially disruptive innovation.

In their analysis of factors affecting chemical innovation during recent decades, Baily and Chakrabarti state that the U.S. has not lacked in invention or creativity, but instead in the ability to capitalize on those inventions. Advances in material science, biotechnology, and in the manipulation of molecular structures could have opened up pathways to innovation in chemistry similar to those seen in other U.S. industries, but their potential was not realized. "The slowdown in the United States …[occurred]… because the U.S. economy failed to incorporate new technology effectively into production…"[7]

[7] Baily, M. N.; Chakrabarti, A. K. *Innovation and the Productivity Crisis*; The Brookings Institution: Washington, DC, 1988.

Figure II-3. R&D Costs as a Percentage of Sales for Chemicals (excluding Pharmaceuticals), 1989-2009



Source: *2010 Guide to the Business of Chemistry*; American Chemistry Council: Rosslyn, VA, 2010; Tables 6.2 R&D Spending in the Business of Chemistry by Segment and 2.6 Chemistry Sales by Industry.

Table II-5. Number of Start-ups Licensing Chemical Technology at MIT by Year, 1990-2009

Year	Total Number of Start-ups	Number of Chemistry Start-ups	Number of Chemical Engineering Start-ups	Number of Life Sciences Chemistry Start-ups	Number of Other Chemistry Start-ups
2009	19	2	7	0	0
2008	21	0	7	0	2
2007	20	0	4	5	2
2006	14	1	2	1	1
2005	13	1	2	0	0
2004	18	2	2	0	1
2003	13	2	3	1	0
2002	26	2	5	4	1
2001	20	1	2	5	2
2000	16	0	2	0	3
1999	17	1	1	2	0
1998	19	0	1	7	4
1997	7	0	0	3	0
1996	6	2	0	1	0
1995	13	0	1	2	0
1994	18	0	2	2	0
1993	14	0	0	2	0
1992	10	1	0	2	0
1991	8	0	1	2	0
1990	6	1	0	0	0
Totals	**298**	**16**	**42**	**39**	**16**
				totals, chemical technologies =	**113**
				% chemical technologies =	**37.9**

Source: Massachusetts Institute of Technology, Technology Licensing Office, Cambridge, MA. Personal communication, 2010.