CATALYST OR SYNTHESIS? CHEMICAL ENGINEERING IN THE LAND-GRANT COLLEGE (1)

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Chemical engineering emerged in the land-grant college system in the early 20th century. The field is a particularly successful example of the fulfillment of the purpose of the Morrill Act of 1862, “to promote the liberal and practical education of the industrial classes in the several pursuits and professions in life” (2). Although the elements of what would become the profession of chemical engineering—chemistry, mechanical engineering and mathematics—were prominent in “liberal and practical” education in the 19th century, it was not until the 20th century that the modern discipline of chemical engineering synthesized in its contemporary form. Land-grant colleges and universities provided a catalyst for this synthesis.

MIT catalyzed the introduction of chemical engineering as a discipline, half a century after its founding as one of Massachusetts’ land-grant colleges. After World War II, Minnesota and Wisconsin’s chemical engineering departments catalyzed the transformation of chemical engineering into an engineering science. Other land-grant colleges and universities emulated and extended the field to meet the needs of their states with engineering experiment stations and other innovations in applied research. At the end of the century, the environmental consequences of chemical engineering presented a challenge to the field’s ability to control the unanticipated consequences of the design and operation of chemical plants, which may provoke a new synthesis in land-grant colleges and universities.

A 19th Century Miscellany

In the 19th century, chemical engineering instruction was a bricolage of coursework in chemistry and engineering, so much so that by the early 20th century chemical engineers found it difficult to define what distinguished their field. At MIT in 1888, Lewis Norton offered the first integrated chemical engineering course “to meet the needs of students who desire a general training in mechanical engineering, and at the same time to devote a portion of their time to the study of the applications of chemistry to the arts, especially to those engineering problems which relate to the use and manufacture of chemical products” (3). The course was a specialty within mechanical engineering, “designed to turn out mechanical engineers with an acquaintance with chemistry” (4).

Elsewhere, schools of mines and metallurgy developed courses in chemical engineering to fit their particular needs. With the advent of electrochemistry, some electrical engineering departments adopted it as a subspecialty. A more typical mixture exemplified at the University of Minnesota, comprised “industrial and applied chemistry” courses that covered “the greater part of technical and analytical chemistry” and offered “the newest and best apparatus.” In order to validate the school learning, excursions were “made to the various industrial and manufacturing establishments in order that the student may become acquainted with the practical and commercial side” (5). At Wisconsin, Engineering Dean J. B. Johnson noted in his 1899 inaugural lecture that

"Chemistry, like electricity, now enters largely into nearly all manufacturing processes." However, he continued, "It is one thing to perform a chemical experiment in a laboratory, in a small way, where the economy of the operation does not enter at all, and an altogether different thing to devise ways and means by which the same thing can be done continuously, on a large scale, in a factory, at such a cost as to make the operation profitable. The man who can do both of these things is the chemical engineer" (6). Administrative recognition of the distinction between chemistry and chemical engineering was an essential ingredient in the resolution of its academic status.

Unlike the German system, where chemists and mechanical engineers collaborated in building the industry (7), most American chemical engineering programs emerged from the disciplinary traditions of chemistry but incorporated elements of other engineering disciplines, metallurgy and mining, that had been earlier responses to industrial developments in the United States. Engineering schools had created new fields in step with the appearance of new technologies, catalyzed by the federal investment in land-grant colleges and universities. Civil engineering spawned mechanical engineering as the triumph of the railroad over the canal required engineers to design as well as drive locomotives. Electrification required electrical engineering as alternating current replaced direct current in order to permit a larger scale of distribution than Edison's Pearl Street station. The late 19th-century growth of heavy chemical industry and steel making spurred the movement of industrial chemists from the laboratory to the pilot plant and factory. In some land-grant colleges, engineers moved to engineering experiment stations.

Engineering Experiment Stations

The association of agriculture with Jeffersonian democracy was an ideological mainstay for land-grant colleges during the first half of their existence. The agricultural experiment stations funded by the Hatch Act of 1887 sought to bring agricultural research to the aid of farmers (8). Some land-grant institutions sought to reach out to industry in similar fashion by creating their industrial analog, the engineering experiment station. Unfortunately, the Association of American Agricultural Colleges and Experiment Stations, which focused on agriculture, did not support the Hale-Dayton bill of 1896 or succeeding attempts to establish engineering experiment stations. Failing to win federal funding, Illinois, Iowa State, Michigan and a score of other land-grant schools established them in cooperation with state government and industry (9). Unlike traditional industries, however, chemical manufacturers operated at a scale that could not be duplicated and was often difficult to reduce to university laboratories, even if the proprietary equipment used was available. MIT's School of Chemical Engineering Practice used industrial facilities identified by trustee A. D. Little and his erstwhile partner, William H. Walker, who became a professor there in 1902 and revamped the Applied Chemistry curriculum. Although some universities built laboratories with half-scale equipment, others relied upon local businesses to show students machinery they would later have to design, maintain, and improve.

For example, Minnesota was unusual in its urban siting for a land-grant university, as was MIT. The agricultural setting of most of the colleges and universities precluded access to the chemical industry, which was heavily concentrated on the eastern seaboard. Minnesota relied upon "the alkali industry, the preparation and use of mordants, soap-making, sugar-making, the production of fertilizers, paints [and] disinfectants" as the staples of their instruction (10).

Illinois, Iowa, and Wisconsin engineering experiment stations focused on agribusiness, which was at least regionally accessible. Farm products converted into an increasingly large number of consumer goods—symbolized by A. D. Little's silk purse from a sow's ear—provided research in a wide variety of subjects (11). In Minnesota, engineers examined uses of marl—an abundant natural resource—for road construction and use in Portland cement (12). Heat transfer processes were also an important subject for the Minnesota engineers, since cold weather was an abundant natural resource (13). By the time Minnesota's engineering experiment station was organized in December 1921, the *Engineering Experiment Station Record* listed over 100 projects in universities throughout the land-grant college system (14). Two years later, the *Record* reported (15)

> The Public is becoming interested and newspapers speak now of engineering research as an actual public necessity rather than a fad or pastime for wizards of science who shut themselves in their laboratories for days at a time and whose results are illustrated in Sunday supplements. Public opinion is being reflected even in these economical days by increased support for engineering investigation and research by the various legislatures now in Session.

The University of Minnesota "Engineering Experiment Station and Bureau of Technological Research" was explicitly modeled on the engineering experiment stations at Illinois and Iowa State, which were supported by appropriations of $90,000 and $45,000, respectively, at that time (16). In 1922-23, the state of Minnesota provided $7800 for its station, of which $4500 came from a "Marl Investigation Fund." The work of the experiment station won early support from a construction company interested in better insulation and from the state highway department (17). Then, as now, winter and road repair dominated the engineering agenda in Minnesota.

MIT School of Chemical Engineering Practice

The architects of the School of Chemical Engineering Practice at MIT were A. D. Little and William H. Walker. Walker came to MIT from Pennsylvania State University in 1900 as an instructor in analytical chemistry. He left MIT to join A. D. Little's consulting firm, where the MIT-trained chemist had already established strong ties with the chemical industry, and after two years returned to MIT to become a professor there. He established a chemical engineering laboratory that rivaled his colleague Alfred A. Noyes' Research Laboratory of Physical Chemistry and eventually eclipsed it (18). A. D. Little served as a member of the Institute's visiting committee for the department of chemistry beginning in 1912 and as its chairman in 1915 reported to MIT's president (19)

> ... the training of chemical engineers involves many problems of unusual difficulty and complexity. The demands upon the members of this comparatively new profession are extraordinarily severe and varied and there is at present no place in the world where a training adequate to these demands may be secured.

Little and Walker led the reformation of the MIT chemical engineering program and in so doing provided a model curriculum for universities throughout the United States. The reform followed a professional campaign to synthesize a new discipline in the American Chemical Society (ACS), the first of many such Divisions the Society embraced in the 20th century.

ACS "Embraces" Chemical Engineering

The ACS was at first reluctant to recognize the hybrid discipline of chemical engineering. It had consolidated regional chemical societies into a national organization in the early 1890s. The ACS claimed to "to represent industrial and commercial chemistry" (20) as well as all other academic branches of chemistry. The rapid rise of chemical engineering in the land-grant schools upset the balance between "pure" and "applied" chemistry and confronted the association with schismatic pressures.

ACS President William F. Hillebrand acknowledged this in his presidential address of 1906. Several specialized chemical societies, including the American Electrochemical Society, had already formed. A new journal, *The Chemical Engineer,* had begun to agitate for a society of chemical engineers. While acknowledging that "technical chemists" were underrepresented both in the society and in its publications, Hillebrand dismissed attempts to form smaller societies as ineffective, recommending instead that the ACS assimilate them and form divisions relevant to their interests. This led in 1908 to the creation of the first ACS Division of Industrial Chemistry & Chemical Engineers (21). It also led to the publication of the *Journal of Industrial and Engineering Chemistry* in the following year. "The Society desires to enlist the cooperation of the Industrial Chemist in this Journal," T. J. Parker wrote in the first editorial. "It does not seek the publication of confidential matters, or the secret processes of any company or works, but it believes that a certain liberality in publishing broader information on subjects of manufacturing interest will be beneficial" (22). Not surprisingly, most American firms had little to offer along these lines. As a result, the first volume of the *Journal* covered a hodge-podge of topics in applied chemistry, including agricultural and food chemistry as well as commercial and industrial topics.

Simultaneously, Little, Walker and a number of practicing chemical engineers created the American Institute of Chemical Engineers (AIChE), which offered membership only to those who had substantial experience in the operation of chemical works (23). Although their creation of the AIChE might have splintered the nascent profession, its exclusive criteria simultaneously neutralized any threat to the larger society. The AIChE provided a separate forum for defining chemical engineering as a discipline, while retaining allegiances to the growing ACS, which provided the means to disseminate specialized knowledge about industrial chemistry and chemical engineering to a much larger audience.

Under the guidance of A. D. Little, the chair of the Division, the *Journal of Industrial and Engineering Chemistry* was reoriented in 1910 to educating American chemists about developments abroad, where the techniques of chemical engineering had enabled the growth of the synthetic chemical industry and propelled Germany to world leadership. Little reported to the society in 1910 that the *Journal* contained articles on chemical analysis, food and agricultural chemistry that did not meet the needs of industrial chemists (24).

Little became ACS president in 1912. He and Walker launched the new discipline of chemical engineering at MIT, beginning with Little's formulation of the "unit operations" concept. It transcended chemical engineering practice and became the basis of the definitive text, *The Principles of Chemical Engineering,* written by Walker and two junior colleagues, Warren K. "Doc" Lewis and William H. Evans (25). Walker and Little persuaded MIT to set up a separate department of chemical engineering after World War I.

Alliances in War and Peace

The "Chemists War" called chemical engineers to manufacture chemicals previously supplied by German factories and to respond to the challenges posed by chemical warfare. The Haber-Bosch process of nitrogen fixation supplied the nitrate explosives the Kaiser used to attack the Allies, and Fritz Haber instituted chemical warfare on a large scale in 1916 when he unleashed chlorine gas at Ypres (26). When America entered the war in 1917, academic chemists went into the Chemical Warfare Service in great numbers. "I have been on the road almost continuously in the government service since the last of April," MIT's Lewis reported to President Richard M. MacLaurin in July, "to organize the chemical research relative to the use of gases in warfare" (27). Colonel William H. Walker took charge of the Edgewood Arsenal, the massive production facility that resulted from that research (28).

Perhaps the most significant aspect of wartime chemical engineering was the production of synthetic organic chemicals previously manufactured in Germany. These "intermediates" not only colored military uniforms but were essential in the manufacture of high explosives. "It should be understood that the equipment and the processes used in making such dyes are very similar to those used in making munitions," DuPont's *Molecules and Man* explained. "It is, therefore, proper to say that a dye plant is a potential munitions factory and, as such, of the first importance to national defense" (29).

The Alien Property Custodian's Office created the Chemical Foundation to make German patents available to the new organic chemical industry spawned by the war. The Foundation survived the attacks of the Harding administration, and succeeded in enacting favorable tariffs that protected the chemical industry in the 1920s. The "Chemists' Crusade" (30), in which the Foundation played a leading role, catalyzed the growth of chemistry and chemical engineering in America in the land-grant colleges, which had been mobilized to train civil, mechanical, electrical and chemical engineers for the war effort (31).

By synthesizing the alliance of chemistry with federal government, military and industrial partners, the Chemical Foundation catalyzed the interwar coalition that saved the Chemical Warfare Service, passed the Fordney-McCumber Tariff that protected the nascent synthetic organic chemical industry and rescued demobilized American chemists from the postwar economic and academic slump (32).

The Spoils of War

Land-grant colleges and universities took the lead in setting up separate chemical engineering departments after the war, when MIT appointed Warren K. Lewis to lead what became the leading chemical engineering department in the nation. Through the AIChE, Little, its president in 1919, rationalized the curricula of the field and provided an incentive for other schools to follow its example. An AIChE curriculum study showed that nearly half of the schools offering chemical engineering courses were land-grant colleges. The AIChE set up an accreditation system for chemical engineering education, the first engineering discipline to do so, and catalyzed the creation of the Engineering Council on Professional Development, which, as ABET, continues to accredit engineering programs today (33).

Land-grant college programs previously had included hundreds of varying courses, not least because each school's service mission to its state seemed to dictate studies of local industry. The new definition of chemical engineering in terms of unit operations transcended the details of most such processes and reduced the curricula to a common focus exemplified, but not defined, by local industrial interests. "Unit operations" became, in effect, a lingua franca for chemical engineers. The first universities to adopt the concept, usually in the form of Walker, Lewis and McAdam's *Principles of Chemical Engineering*, were able to transform their existing facilities into unit operations laboratories. At the University of Minnesota, one chemist wrote, "The underlying philosophy of chemical engineering ... is embodied in the definition of the profession propounded in 1922 by the American Institute of Chemical Engineers"

(34). Within a few years, Iowa State, Michigan, Ohio State and Wisconsin were also accredited by the AIChE.

The historical synthesis of chemical engineering in land-grant colleges and universities required the ingredients of industrial technique, chemical understanding, and government funding, the high pressures and temperatures of World War I, and the catalyst of the unit operations concept, which transformed a heterogeneous field into a profession with a standard curriculum, method and definition. The stability of the synthesis through the depression and World War II testified to the durability of the catalyst, which remained unchanged as chemical engineers developed the petroleum industry, synthetic fibers, plastics and what was, increasingly, an engineered environment where automobiles in coats of many Du Pont colors edged out the legions of black Fords, traversed the nation on roads composed of engineered materials, and carried not wood or metal appointments but plastic seats, dashboards and steering wheels. The efficacy of the refining of industrial chemistry into chemical engineering, like catalytic cracking of crude petroleum and polymerization of simple molecules into resilient nylon, transformed the world of the chemical engineer just as his art limned the nation with synthetic colors and materials.

Engineering Science Crystallizes

Although chemical engineering, like its physical counterpart, electrical engineering, tamed the effluence of American industrial innovation into a comprehensible stream of technology, unit operations, like "Moore's law" in modern computer science, was an artificial rather than a fundamental scientific principle. Since, like computers, industrial processes do evolve incrementally, and since the vitality of both electrical and chemical engineering found both fields inadequate to the challenges posed by such new innovations as radar and transuranic chemistry, the formulation of engineering science in the wake of World War II required a resort to more fundamental scientific discoveries that made it possible not only to deal with scaling up, but also with scaling down to the atomic and subatomic levels encountered in nuclear science and quantum electronics. Since both of these enterprises were inescapably mathematical, this transformed chemical engineering into a discipline that drew from new scientific and mathematical techniques the inspiration for further progress.

The architects of the reformation of chemical engineering were also found in land grant schools, in particular Minnesota and Wisconsin, where transport processes and mathematical analysis of reactions became the new focus in the postwar period. Engineering science emerged as empirical studies were reduced to mathematical formalisms characteristic of advanced analyses of flow, like the Reynolds number, the Prandtl number and other dimensionless quantities, revealing fundamental knowledge that was not derived directly from, nor the result of, the application of preexisting scientific knowledge like chemistry (35). The "Minnesota-Wisconsin Revolution" catalyzed the crystallization of chemical engineering as an engineering science.

Minnesota contained chemical engineering in its school of chemistry until the late 1940s, when saturated enrollments precipitated chemical engineering into a new department. It was blessed with a new building but few other resources (36). A chemical engineer turned mathematician, Neal Amundson, became its head and hired new staff, including mathematical prodigies like Rutherford Aris as well as chemical engineers, biochemists and other scientists who refined graduate education into engineering science. Aris, who had worked for Imperial Chemical Industries (ICI) designing chemical reactors, had already demonstrated the importance of mathematical analysis in chemical engineering. Aris, whose eminence in the study of ancient inscriptions rivaled his fame in chemical engineering wrote (37)

> In the 50's at Minnesota, Neal Amundson began to show the power of ... "thatt supersensuous sublimation of thought, the euristic vision of mathematical trance," (as Bridges calls it) and the triumvirate of Wisconsin were to write that famous book which can be read either by rows or columns. Nuclear engineering was recognized as cousin german to chemical; biochemistry was her wash pot and over biology itself she had cast her shoe.

The famous book was *Transport Phenomena* by R. Byron (Bob) Bird, Warren E. Stewart, and Edwin N. Lightfoot. The Wisconsin engineers provided a new paradigm—flow and transport processes—that transcended unit operations. Olaf Hougen and Bird reduced the heterogeneity of unit operations into material transport processes that were more easily captured in the differential equations computers could solve more effectively than human calculators. Amundson and Aris computerized the calculations of chemical engineering that applied mathematics to these processes making them more accessible to their colleagues, who had relied upon more empirical techniques.

The Minnesota-Wisconsin revolution, with its heavy doses of math and science, spread through the graduate programs in chemical engineering just as unit operations had through chemical engineering programs, with a salutary effect on the accelerated development of nuclear and chemical technology in the postwar era (38). Enrollments continued to increase as federal funding supplemented industrial investment in chemical engineering education (39).

Bhopal and Better Living

The scientific sophistication of chemical engineering at MIT, Minnesota and other land-grant universities overshadowed the traditional concerns of these schools for democracy and social consciousness. While graduates of these programs were better researchers and teachers, they were less concerned with the humanitarian and ethical aspects of engineering than the increasing impact of chemical technology required (40). Academic chemical engineering was increasingly remote from practice, especially in underdeveloped parts of the world. While chemical engineers could rejoice that Norman Borlaug made substantial use of their products in the Green Revolution of the 1960s, and industry reveled in slogans like "Better Living through Chemistry," the environmental movement, beginning with Rachel Carson's *Silent Spring,* challenged the short-sighted application of chemicals like DDT, the engineering of lead into gasoline to provide antiknock protection, and other unintended consequences of 20th-century chemical engineering. This was in part a consequence of the privatization of research in chemical engineering in land-grant universities and colleges, where industrial interest trumped democratic concerns about the effects of chemical technology. While private universities owe nothing to such concerns, the Land-Grant Colleges and Universities do, by virtue of the public support afforded them by federal and state governments (41).

The prestige enjoyed by chemical engineers in industry and academe plunged precipitously in the 1970s, as a series of environmental and industrial disasters called into question the efficacy, if not the ethics, of the profession. The 1976 chemical spill at Serveso, Italy, was a harbinger of these events. "More than a chemical engineering disaster," in the words of a recent analysis, "Serveso is a useful reminder to engineers to be ever mindful of the first canon of their profession ... to hold paramount the health, safety, and welfare of the public" (42).

The Bhopal disaster eight years later reinforced the impact of the Serveso disaster on chemical engineering. Union Carbide chemical engineers who designed the plant were blamed for their evident inability to successfully transfer the methyl-isocyanate (MIC) production technology to a third-world setting, and while the parent company's lawyers minimized the damages, they did not succeed in convincing the world that sabotage was the sole cause of the failure of the plant's safety system (43). The academic-industrial coalition that had launched the profession at MIT chose to support the American multinational's assumption of victimhood in the face of legal and environmental onslaughts (44). Although controversy and litigation continues, public concern about the incident escalated after leaks from the Union Carbide MIC plant in Institute, West Virginia, revealed deficiencies similar to those alleged at Bhopal. Subsequent historical analyses have remained critical of Union Carbide's role, especially after it "lawyered up" to avoid indictments in American courts and extradition of its chief executive to India (45). As a result of the public concern, the National Academy of Engineering prescribed a case study of the accident, ABET instituted new requirements of engineering schools for engineering ethics education (but found them to be poorly received) (46). A National Research Council Study of *Frontiers in Chemical Engineering* chaired by Amundson recommended a modicum of design and safety modifications in response to what they considered an unrealistic desire for "no risk" and focused on the financial risks inherent in such cases (47).

The origins of chemical engineering in the land-grant college system did not insulate the profession from the corporate society that it primarily serves. Although our universities and colleges can do more to inculcate the independence of engineering in corporate settings, it will require a reformulation of the original goal—"to promote the liberal and practical education of the industrial classes"—to ensure chemical engineers "hold paramount the safety, health and welfare of the public and protect the environment in performance of their professional duties" (48).

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About the Author

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The 2014 HIST Award in the History of Chemistry

The History of Chemistry Division of the American Chemical Society is pleased to announce Professor Ernst Homburg as the winner of its 2014 HIST award. This international award for contributions to the history of chemistry has been granted since 1956 under sequential sponsorships by the Dexter Chemical Company, the Edelstein Foundation, the Chemical Heritage Foundation, and the History of Chemistry Division. The event, consisting of a monetary presentation, a plaque, a symposium honoring the work of Professor Homburg, and a lecture by the awardee, will take place on 12 August 2014 at the American Chemical Society's annual meeting in San Francisco, California.

The 2014 winner, Ernst Homburg, was born in 1952 in Venlo, The Netherlands. After studying at the Protestant Lyceum, he studied at the Municipal University, Amsterdam, where he received M.Sc. in chemistry and at the University of Nijmegen where he received a Doctoral degree in History. From 1972 to 1993 he served at various posts in history and technology at the Universities of Amsterdam, Groningen, Nijmegen, and Eindhoven. From 1993 to present he has served as Assistant Professor, then Professor, in the Department of History at the University of Maastricht, The Netherlands. With his broad background, Dr. Homburg is one of the leaders in the history of modern chemical industry and technology. He has been involved as a co-organizer and writer in two multi-volume book series on the history of European technology in the 19th and 20th centuries, as well as a multitude of other books and papers. He has been president of a number of organizations that have promoted the history of technology and science throughout Europe and other parts of the world. As an influential speaker, Dr. Homburg is known for his conciseness and fresh viewpoints, with an ability to change viewpoints without any display of ego or discourtesy.