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Chemical Industry in China, 1860–1949

By *James Reardon-Anderson**

IN THE COURSE OF A CENTURY that ended in 1949, China established a modern chemical industry. Chemical industry is the branch of manufacturing that converts raw materials to products by the rearrangement of atoms and molecules, rather than simply physical or mechanical changes in the size, shape, or pattern of assembled parts. In very early times, of course, the Chinese founded many industries that meet this definition, including the manufacture of paper, ink, dyes, explosives, and porcelain. The term *modern* applies only to industries that employ power-driven machinery and in the case of China means those that use methods and equipment discovered or invented in the West and introduced into China beginning in the mid-nineteenth century. Even this definition, however, is excessively broad, covering the manufacture of glass, soap, matches, refined sugar, and many other products made in China during the past hundred years. This study, which covers 1860–1949, will adhere to a narrower definition that includes producer goods, particularly acids, alkalis (sodas), and coal tar, and other materials that played a special role in China, such as chemical fertilizer, alcohol, and liquid fuels.

The development of Chinese industry in general and the producer goods sector in particular was constrained by the essentially premodern economy of late nineteenth- and early twentieth-century China. During the period covered by this study, the economy of China grew at a moderate pace, about as fast as the population, but changed little structurally, with agriculture and handicrafts dominating throughout. The supply of land, labor, and capital, as well as the occupational and income distribution within Chinese society, remained unchanged. Agriculture continued to account for about three fifths of China's gross national product, while within the manufacturing sector handicraft production remained three times as great as modern factory output. By the middle of the twentieth century, China was still a huge, slowly moving agrarian machine.[1]

While the macrostructure of the Chinese economy changed little, modern

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[1] Albert Feuerwerker, *Economic Trends in the Republic of China, 1912–1949* (Ann Arbor: Center for Chinese Studies, Univ. Michigan, 1977), pp. 1–16, on p. 12, citing figures from Liu Ta-chung and Yeh Kung-chia, *The Economy of the Chinese Mainland* (Princeton: Princeton Univ. Press, 1965), p. 66.

Throughout this article, the term "ton" means "metric ton" and is equal to 1,000 kilograms or 2,205 pounds avoirdupois. Chinese weights have been converted as follows: one *catty* equals 1.33 pounds; one *picul* equals 133 pounds. Unless otherwise noted, dollars ($) means U.S. dollars. For conversion of American to yuan, or Chinese dollars, see Cheng Yu-kwei, *Foreign Trade and Industrial Development of China* (Washington, D.C.: University Press of Washington, D.C., 1956), pp. xi, 262–263. For Chinese characters for names of individuals and institutions mentioned in this article, see appendix.

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industries did take root. As early as the 1860s, provincial officials established enterprises to manufacture ships, guns, and other products related to the nation's defense. After 1900 factories employing power-driven machinery and modern techniques sprang up in and around the treaty ports. The number of Chinese-owned factories of this type increased from a few hundred in 1913 to a few thousand in 1933, and during the period 1912–1936 their output grew by an impressive 9.4 percent per year.[2]

It is important to recognize both the extent and the limits of this industrial activity. At the peak of its development, in the 1930s, the modern factory sector accounted for only 2 percent of China's gross domestic product, and only one quarter of factory output was composed of producer goods. Chemical products accounted for less than 5 percent of all modern manufactures, while most "chemicals," such as matches, cosmetics, paper, and glass, were produced for personal consumption rather than industrial use. In short, this study examines a very slender slice of the Chinese economic pie. Still, in one corner of that country was assembled a critical mass of capital, machinery, and skilled manpower that contained the key to China's future economic growth. The significance of the story lies in this qualitative, rather than any quantitative, measure.[3]

An important factor governing development of China's economy was the political instability that the country experienced during the early twentieth century. Foreign invasion and internal rebellion combined to weaken the last dynasty, the Ch'ing, which teetered through its later years and collapsed in 1911. Under imperial rule, the program to introduce new technologies was limited to the military sector and offered little scope for the manufacture of chemicals. A republic was founded in Peking in 1912, but after the death of the first military strongman, Yüan Shih-kai, in 1916, China was rocked by more than a decade of conflict among regional warlords, none of whom could either unify the country or remain satisfied with only one piece of it. Under these circumstances, few Chinese were willing to risk the introduction of new technologies or the large investments required by the modern chemical industries.

The turning point came in 1928, when the Nationalist (or Kuomintang) regime, led by Chiang Kai-shek, unified much of the country and established a new republic with its capital in Nanking. The Nanking Decade, 1928–1937, witnessed achievements in several fields, including the introduction of state-of-the-art techniques for the manufacture of industrial chemicals. This period ended abruptly with the Japanese invasion, which forced the Nationalists to retreat from the modernizing cities along the coast to the less-developed hinterland of western China. During the war, the Chinese registered a different kind of progress, building new industries in chemicals and other fields using only local resources and their own ingenuity. After 1945 attempts were made to restore the economy of urban China, but the civil war and the general chaos accompanying it overwhelmed these efforts, leaving the task of rebuilding China to the Communists, who took over in 1949.

[2] See John K. Chang, *Industrial Development in Pre-Communist China: A Quantitative Analysis* (Chicago: Aldine, 1969), p. 71; and Feuerwerker, *Economic Trends* (cit. n. 1), pp. 17 ff.

[3] Feuerwerker, *Economic Trends*, p. 12, summarizing data by Liu and Yeh and others. Figures for chemical products are based on the 1933 survey by D. K. Lieu, discussed later in this study (see n. 55 below).

CHINESE CHEMICAL INDUSTRY BEFORE 1928

Prior to 1928 the Chinese manufactured few chemicals on a large scale or by modern means. The first producers to enter this field were the government arsenals, which made acids needed for the production of gunpowder and other explosives. New enterprises were created to turn out a variety of simple consumer products via the chemical transformation of raw materials. The most important of these products, soap, paper, and glass, provide a backdrop to this study; one of them, the seasoning monosodium glutamate, will be discussed in some detail. Only one factory was erected to manufacture a basic industrial chemical, soda ash, by then-current techniques. Before the coming of the Nationalists, China had no nationwide program of economic development. The founding of the chemical industries depended upon the demands of the military and the success of a few farsighted individuals.

Military Manufactures

Modern machine-manufacturing began in China in the late 1860s under the direction of provincial officials whose purpose was to enhance the military strength of the empire, then threatened by rebellion at home and invasion from abroad. Arsenals and shipyards, built near major coastal cities, were the first centers of modern industry and of the ideas and techniques upon which that industry rested. The arsenals made guns, large and small, and the explosives used in them. The making of gunpowder prompted manufacture of China's first industrial chemicals, sulfuric and nitric acids.

The dominant military explosive of the mid-nineteenth century, and of the preceding millennium, was a mixture of saltpeter (potassium nitrate), charcoal, and sulfur commonly called black gunpowder, or simply gunpowder. Invented in China in the ninth century, gunpowder reached Europe via the Middle East; subsequently, production techniques were refined and reintroduced into China, where knowledge of its manufacture and use had lagged. Chinese production of gunpowder by machine methods began in the 1870s at government arsenals in Shanghai (Kiangnan), Tientsin, and Nanking. Tientsin, the largest plant, produced 275 tons per year.[4]

While the reaction among substances contained in it produces a bang, black gunpowder itself is a physical mixture, whose manufacture does not involve chemical transformations or the consumption of prepared compounds. These refinements came later, with the introduction of smokeless powder. Smokeless gunpowder, as it is now known, was first produced in France in 1884, came into general use by European armies after 1900, and was the chief propellant employed in World War I. The basic component of smokeless gunpowder is nitrocellulose, or guncotton, which is made by treating cotton fibers with sulfuric and nitric acids. The advantage of smokeless over black gunpowder is that it is almost entirely converted to gas, so that a smaller charge produces greater force.

[4] On the invention of gunpowder, see Joseph Needham, *The Grand Titration: Science and Society in East and West* (London: Allen & Unwin, 1972), pp. 65 ff; on Chinese production, see Thomas L. Kennedy, *The Arms of Kiangnan: Modernization in the Chinese Ordnance Industry, 1860–1895* (Boulder, Colo.: Westview Press, 1978), pp. 62–75, 114–118.

The absence of smoke also made it easier to operate the quick-firing guns and magazine rifles introduced around the turn of the century.[5]

The Lung-hua Powder Plant, attached to the Kiangnan arsenal near Shanghai, was the first in China to make smokeless powder. In 1890 Kiangnan introduced a modified British Lee rifle, which required the new type of propellent. While ammunition of this type could be and was imported, in 1895 the arsenal purchased a complete set of German equipment for the manufacture of nitric acid, guncotton, and smokeless powder. A German technician was engaged to put this machinery into operation but failed, claiming that the equipment was inoperable in the climate of China. Chinese staff at Lung-hua took over and soon achieved results: by 1905 production of smokeless powder reached twenty-seven tons per year. In the process employed at Lung-hua, nitrates were reacted with sulfuric acid to produce nitric acid, and these acids were used to treat cotton. Temperature, pressure, and density of the liquids were monitored at each step to ensure successful results. At first all sulfuric acid was imported; later, probably before the outbreak of World War I, both Kiangnan and Hanyang arsenals began to make their own. During the 1920s manufacture of modern explosives spread to government arsenals throughout China.[6]

Prior to 1927 all sulfuric acid in China was made by the lead-chamber method. This method was invented in England in 1746 and came into wide use during the nineteenth century, when the demand for sulfuric acid as an intermediate in the manufacture of soda, bleaching powder, and other products rose rapidly. The chambers were made of riveted lead sheets enclosing a space of several hundred cubic feet or more and were built atop sand or stone foundations. Saltpeter and sulfur-bearing substances, generally iron pyrites or brimstone, were placed in the chamber and ignited. Gases from the combustion condensed on the walls of the chamber and were absorbed by a layer of water that covered the floor. After repeated burning over a period of weeks, the acidified water was withdrawn and boiled down to condense the acid. The chambers were easy to construct, the raw materials widely available. The product, as much as 66 percent pure, was strong enough for most requirements and could be concentrated by other techniques when necessary. Sulfuric acid was combined with potassium or sodium nitrate, also readily available, and heated to produce nitric acid.[7]

Despite the sensitive nature of their work, Chinese arsenals relied heavily on foreign machinery, supplies, and advice. When he built his first arsenal, at An-

[5] Ormond Lissak, *Ordnance and Gunnery* (New York: Wiley, 1915), pp. 1–15.

[6] *North China Herald,* 26 Apr. 1895, p. 612; 16 July 1897, p. 130, column 3; Wei Yün-kung, ed., *Chiang-nan chih-tsao-chü chi* (Record of the Kiangnan Arsenal) (Shanghai: Shang-hai wên-pao shu-chü, 1905), *2*:37, *3*:76, *9*:7–10; Minami Manshū tetsudō kabushinki gaisha, Tenshin jimusho chōsaka (South Manchurian Railway Company, Tientsin Work Investigation Section), *Shina ni okeru san sōda oyobi chisso kōgyō* (China's acid, soda, and nitrogen industries) (Tientsin, 1937), pp. 123–124. I would like to thank Thomas Rawski for suggesting this source and offering other helpful advice.

[7] On the chamber method, see L. F. Haber, *The Chemical Industry During the Nineteenth Century: A Study of the Economic Aspect of Applied Chemistry in Europe and North America* (Oxford: Clarendon Press, 1958), pp. 1–8. On the manufacture of acids in China, see Ch'ên T'ao-shêng, "Hu-Han hua-hsüeh kung-yeh k'ao-ch'a-chi" (Report on an investigation of the chemical industries of Shanghai and Hankow), *Hua-hsüeh kung-yeh* (Chemical Industry) (Peking/Shanghai/Chungking, Chinese Society of Chemical Industry), Jan. 1924, *2*(1):211–252, on pp. 234–240; and Wei T'ing-ying, "Chi-nan, Ch'ing-tao, Tê-chou, T'ang-shan, T'ang-ku hua-hsüeh kung-yeh k'ao-ch'a-chi" (Report on an investigation of the chemical industries of Tsinan, Tsingtao, Tehchow, Tangshan, and Tangku), *ibid.,* July 1924, *2*(2):201–220, on p. 212.

king in 1861, the viceroy Tsêng Kuo-fan intended to cast cannon and build steamships with the help of China's own scientists and engineers. But his successor, Li Hung-chang, showed that European experts achieved better results. Prior to World War II, all major Chinese powder factories were established using British or German equipment, under the guidance of directors from these two countries, and with the operational support of foreign technicians. Attempts to replace the foreigners with Chinese were never entirely successful. In the 1920s the largest government arsenal, at Mukden, employed more than fifteen hundred foreigners, most of them in technical areas. The other major plants, at Taiyuan, Hanyang, and elsewhere, also depended on foreign equipment and advice.[8]

Information on the arsenals is sketchy, but on the whole they were not a great success. The manufacture of ordnance was expensive, the products of uneven quality, and the output limited. Those responsible for China's defense generally found that it was better to buy arms than to make them. Some of the largest and most modern arsenals were in Manchuria, which was lost to the Japanese in 1931. The Hanyang arsenals, which reached a peak production of 120 tons of sulfuric acid and 20 tons of gunpowder per month, declined, along with the Chinese iron industry, in the early 1920s and began importing all its metals and explosives. By the mid-1930s the Kung-hsien (Honan) and Canton arsenals were still in operation, but many of the other powder factories in China had shut down.[9]

Civilian Manufactures

Modern machine production in the civilian sector trailed that in the military by several years. Prior to 1900 the Ch'ing dynasty saw no need for general industrial development and permitted creation only of those official enterprises whose existence could be justified by military exigencies. After the stunning defeat at the hands of the Japanese (1895) and the humiliation of the Boxer Rebellion (1900), however, foreigners won the right to erect factories in China, and Peking encouraged its subjects to do the same. In rapid succession, new enterprises were established, especially in the treaty ports, where foreign influence was greatest. Most of these produced consumer goods, led by textiles and food; this category also includes "chemical" products, such as matches, soap, glass, paper, bleach, dyes, and drugs. Agricultural and mineral inputs for these industries were available locally, but all prepared chemicals were imported.

Foreign importers and manufacturers dominated the modern sector until World War I, when native Chinese industry made its first significant advance. The war brought a rise in price and decline in supply of foreign goods of all types and enabled local producers to enter markets previously controlled from abroad. The creation of new markets through foreign initiatives, followed by successful

[8] See Kennedy, *Arms of Kiangnan* (cit. n. 4), pp. 35–36, 40–41, 52–53, 62–64, 72–75, 114–115, 134, 142; and on foreign advice see also Anthony B. Chan, *Arming the Chinese: The Western Armaments Trade in Warlord China, 1920–28* (Vancouver: Univ. British Columbia Press, 1982), pp. 110–112; and *The China Year Book* (Shanghai: North China Daily News & Herald), 1933, pp. 544–546; 1936, pp. 428–430.

[9] See Chan, *Arming the Chinese* (cit. n. 8), pp. 112–114; Ch'i Hsi-sheng, *Warlord Politics in China, 1916–1928* (Stanford: Stanford Univ. Press, 1976), pp. 116–120; and, on Hanyang, Wu Ch'êng-lo, "Chung-kuo hua-hsüeh kung-yeh shê-chi chi yüan-liao wên-t'i" (Question of plans and materials for the Chinese chemical industry), *Hua-hsüeh kung-yeh*, Oct. 1929, *4(2)*:5–21, on p. 5.

import substitution on the part of local manufacturers, emerged in this era as a dominant pattern of China's industrial development. While the primary motive of early Chinese industrialists was profit, native industry was also spurred by the growing spirit of nationalism. The decision reached at the Versailles peace conference in 1919 to assign German holdings in the Far East to Japan prompted an outpouring of indignation in China. Anti-imperialist sentiment, coupled with the return of European products to the Chinese market, gave local manufacturers ample incentive to join the boycott against foreign goods. On both economic and moral grounds, the "made in China" movement attracted many enthusiasts.

While more than a few Chinese were willing to join the battle for self-sufficiency, the problems of setting up and operating a modern factory were enormous, particularly in fields that required sophisticated technologies and quality controls. In many cases, industrial pioneers possessed only the most rudimentary knowledge of their trade, designing their plants without blueprints and running them without the aid of foreign advisors. One report on an acid factory in central Shantung, where pyrites were plentiful and fuel cheap, demonstrates the difficulty of this task:

> On arrival, our surprise was exceeded only by a certain amount of pathetic admiration. A couple of thousand dollars, all the money the investors possessed, had been expended in the erection of a small plant for the manufacture of sulfuric acid by the chamber process. There were four little lead chambers in a row, a pyrite burner was located at one end and at the other end was an outlet pipe for the excess gases. The manager, who was a high-school graduate and had studied a half year of chemistry in high school, stepped proudly forward, and explained that he had designed the plant unaided and that the completed plant was an exact copy of the diagrammatic sketch which was to be found in his high school textbook. The plant had failed to produce satisfactory acid. The "company" was profoundly disappointed when shown that there were a number of important details which had been omitted in the crude sketch. This is not an isolated case of patriotic enthusiasm.[10]

Fan-Hsü-tung

Other Chinese manufacturers achieved greater success, among them Fan Hsü-tung (Fan Jui), founder of the modern chemical industry in north China. Fan was born in 1882 in Hsiang-yin, a market town near Changsha, the capital of Hunan Province. His elder brother, Fan Yüan-lien (Fan Ching-shêng), was a follower of the reformer Liang Ch'i-ch'ao, and the two brothers attended the Academy of Current Affairs in Changsha, where Liang served as dean of students. After the aborted reforms of 1898, the Fans followed Liang to Japan, where Hsü-tung completed middle school and studied chemistry at one of the imperial universities. They returned to China in 1912, after the establishment of the new republic. Yüan-lien quickly emerged as an important figure in the Progressive party and used his official connections to promote the fortunes of his younger brother, first in arranging for Hsü-tung to join a delegation to Europe to study industrial development and reform of the salt administration.[11]

[10] William Henry Adolph, "Chemical Industry in China," *Journal of Industrial and Engineering Chemistry*, Dec. 1921, *13*(12):1099.

[11] On Fan Hsü-tung (Fan Jui), see Ch'ên Chên and Yao Lo, eds., *Chung-kuo chin-tai kung-yeh-shih tsŭ-liao* (Materials on China's modern industrial history) (Peking: San-lien shu-tien, 1957), Vol. I, pp. 513–520; Chih Fêng, "Fan Hsü-tung: wo-kuo hua-hsüeh kung-yeh ti t'o-huang-chê" (Fan Hsü-tung:

The Chinese, of course, knew a great deal about salt; controversies over production, marketing, and government control had fueled debate in China for millennia. In 1913, however, Yüan Shih-kai, the military strongman who dominated the republic during its early years, put up the salt tax as collateral on a foreign loan, the terms of which required reform of the salt administration. The delegation on which Fan served was charged with finding a way to implement this agreement. Fan was impressed by his first view of the West, particularly Germany, and returned with ideas about the development of Chinese industry. By this date, foreign importers had introduced refined salt into China and demonstrated the profitability of its sale for both personal consumption and industry. After a visit to the Changlu salt fields in north China, Fan resolved to set up his own company and compete for a share of this market.

The Chiu-ta Refined Salt Company was established in 1914 as a joint stock company with an initial capital investment of 50,000 yuan. According to one source, the money was raised through the influence of Fan Yüan-lien and other officials of the Peiyang government—a plausible assertion, since the manufacture and sale of salt in China had been a government monopoly and creation of a private corporation for this purpose would require official sanction. Located in Tangku, on the coast of north China near Tientsin, the Chiu-ta factory could draw on an already established industry, which produced salt by the evaporation of seawater, and transport its products by water or rail to most of the major cities of China. The crude brine was refined using soda ash and lime to precipitate the impurities, a technique that differed little from traditional methods except in using high-grade imported soda rather than raw ash. The business was an instant success, and rapid expansion followed. By 1930, the company's assets were worth over two million yuan.[12]

While refined salt (sodium chloride) was sold for personal consumption, by far the largest market for this substance was manufacturers of industrial chemicals, especially soda. Soda, or soda ash (sodium carbonate), and the other chemicals related to it—sodium hydroxide (caustic soda), bicarbonate (baking soda), silicate, and sulfide—are used in the manufacture of soap, paper, glass, textiles, dyes, drugs, foods, and other products. The growth of these industries in nineteenth-century Europe was made possible by the discovery of methods for making soda on a massive scale. By 1914, annual world production of sodium carbonate was around three million tons.[13]

Natural soda has been known to man since prehistoric times. The name soda

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Trailblazer of our country's chemical industry), *Chung-kuo k'o-chi shih-liao* (China historical materials of science and technology) (Peking), Dec. 1980, *3*:2–9. These sources and *Shina kōgyō* (cit. n. 6), p. 5, agree that Fan studied chemistry, but each places him in a different Japanese imperial university. Fan Yüan-lien (Fan Ching-shêng) was actually Hsü-tung's cousin, raised in Hsü-tung's home after the death of his own father. In biographies of Hsü-tung, Yüan-lien is referred to as the "elder brother," and the two boys probably viewed their relationship in this way. For details on Fan Yüan-lien, see Howard Boorman, ed., *Biographical Dictionary of Republican China* (New York: Columbia Univ. Press, 1967), Vol. II, p. 14.

[12] On Fan Yüan-lien's role, see Chih Fêng, "Fan Hsü-tung" (cit. n. 11), p. 4; on Chiu-ta, see Ou-yang I, "P'ing-tung hua-hsüeh kung-yeh k'ao-ch'a-chi" (Record of an investigation of the chemical industries east of Peiping), *Hua-hsüeh kung-yeh*, Feb. 1930, *5(1)*:77–110, on pp. 91–95; on the traditional salt process, see Li Ch'iao-p'ing, *The Chemical Arts of Old China* (Easton, Pa.: Journal of Chemical Education, 1948), pp. 54–65.

[13] Hou Tê-pang, *Manufacture of Soda with Special Reference to the Ammonia Process* (1934; New York: Hafner, 1969), p. 41.

ash comes from the fact that sodium carbonate was originally obtained by burning seaweed or other plants and leaching the ashes in hot water to produce a brown lye used in domestic laundering. More recently, large quantities of natural soda have been found in crystalline or powdered form on the earth's surface and dissolved in lakes in arid regions. Manchuria and Inner Mongolia have many soda lakes, and by the nineteenth century local inhabitants were cutting blocks of ice from the frozen surfaces and transporting them to centers such as Changchiakou, along the Great Wall west of Peking, for refining and marketing throughout north China. At the turn of the century, production of natural soda reached 200,000 tons per year. Because of its low quality (only 45–50 percent sodium carbonate) and the high costs of transportation and refining, however, the natural product could not compete with synthetic soda for industrial use.[14]

Until the early 1920s China's only source of industrial-grade soda was from abroad, primarily from Brunner-Mond and Company of England, the world's largest producer. After the outbreak of World War I, however, English producers refused to divert the supply of this chemical, then running around 20,000 tons per year, from Europe. During the next few years, the price of soda in China rose to seven or eight times its prewar level, and many factories that manufactured glass, soap, paper, and other products were forced to close. Loss of the foreign supply was a devastating blow to industries that depended on soda, but it also provided an opportunity for Chinese to enter this field on their own.[15]

No one was in a better position to seize this opportunity than China's foremost maker of salt, Fan Hsü-tung. At the outset, Fan's problems were legal and financial. The first republican government maintained the traditional Chinese view of salt as a consumer product to be tapped as a source of revenue and taxed refined salt at ten to twenty times its market price. Finally in 1917, through the influence of officials connected to the salt administration, who later joined Fan to found China's first soda factory, the government announced an exemption from tax on salt purchased for industrial use. With this concession in hand, Fan assembled a group of investors to establish the Yungli Soda Manufacturing Company. The initial capital of 300,000 yuan came primarily from profits on the sale of Chiu-ta salt and investments from two banks: the Kincheng Bank of Tientsin and the Shanghai Commercial and Savings Bank. The founders of these banks, Chou Tso-min (Kincheng) and Ch'ên Kuang-fu (Shanghai), sat on the Yungli board of directors and played a major role throughout the republican period in the development of Chinese chemical and other industries.[16]

Fan Hsü-tung planned to locate the Yungli factory alongside the Chiu-ta plant in Tangku, close to the raw materials and transportation facilities, but there remained problems of equipment and technology. In addition to Fan himself, one third of Yungli's founders were men with technical training in China or abroad.

[14] *Ibid.*, pp. 14–30; and Kuo Pên-lan, "Chang-chia-k'ou chih liang ta hua-hsüeh kung-yeh" (Two great chemical industries of Changchiakou), *Hua-hsüeh kung-yeh*, July 1923, *1(2)*:137–139.

[15] For Chinese soda imports, see Table 2 below; on the impact of the war, see Ou-Yang I, "P'ing-tung k'ao-ch'a-chi" (cit. n. 12), pp. 97–98.

[16] See Ch'ên Chên and Yao Lo, eds., *Kung-yeh-shih tsŭ-liao* (cit n. 11), pp. 514–516; Chih Fêng, "Fan Hsü-tung" (cit. n. 11), p. 6; Ou-Yang I, "P'ing-tung k'ao-ch'a-chi" (cit. n. 12), pp. 97–106; Liu Ta, "Wo-kuo chih-chien kung-yeh yü Ying-kuo Pu-nei-mên kung-szŭ ti tou-chêng" (Struggle between our country's soda industry and the Brunner-Mond Company of England), *Chung-kuo k'o-chi shih-liao*, Oct. 1980, *2*:101–103; Fan Jui [Fan Hsü-tung], "Yung-li chih-chien kung-szŭ ta-shih-chi" (Description of the Yungli Soda Manufacturing Company), *Hua-hsüeh kung-yeh*, Jan. 1924, *2*(1):253–260.

Figure 1. Chiu-ta Refined Salt Company. From Sung-ho Lin, Factory Workers in Tangku *(Peking: Social Research Department, 1928).*

During the early years, recruiters were sent to high schools and colleges in China and the United States in search of people to staff the new enterprise. Among those hired in America were some of the future leaders of Chinese chemical engineering, including Wu Ch'êng-lo, Leo Shoo-tze, and Hou Tê-pang. From the outset, all agreed that China should produce soda by the state-of-the-art technique, the Solvay or ammonia process. Developed by a Belgian, Ernest Solvay, in the 1860s, this process had displaced the older Le Blanc method and by the end of World War I accounted for virtually all manufactured soda. The Solvay cartel was controlled by a small number of very large producers, led by Brunner-Mond, whose dominant position ensured a high degree of secrecy in all phases of the business. Since Yungli was not a member of the cartel, it could not obtain the license, equipment, or technical assistance to build and operate a plant of this type. Fan reportedly paid $20,000 for stolen blueprints of an American Solvay factory, but these proved too crude to be of any use. In the end, the Chinese had to figure things out for themselves.[17]

The man most responsible for ferreting out the secrets of this industry and applying them successfully in China, and the outstanding figure in Chinese chemical engineering during the first half of the twentieth century, was Hou Tê-pang. Hou was born in 1890 in a village south of Foochow, Fukien Province, one of the ports through which modern notions of science and technology first reached the Chinese. He was from a farming family of modest means, received some education in his village, and went on to study in Shanghai, where he graduated in 1908 from the Fukien-Anhwei Railroad School. After two years of work as a railroad construction supervisor, Hou passed the national examination to qualify for a Boxer indemnity fellowship. This led to two years of preparatory study in Peking, followed by a B.S. from the Massachusetts Institute of Technology (1917) and a Ph.D. from Columbia University (1921), both in chemical engineering. After graduation, Hou joined the Yungli corporation as its chief engineer. During the next decade, he traveled between the United States and China, studying the

[17] On Yungli technical personnel, see Ch'ên Hsin-wên, "Chi Yung-li hua-hsüeh kung-yeh kung-szŭ p'ei-yang jên-ts'ai ti tso-fa" (Record of the methods of developing human resources of the Yungli Chemical Industry Company), *Chung-kuo k'o-chi shih-liao*, Sept. 1981, *3*:28–34; on the history of the soda industry, see Hou Tê-pang, *Manufacture of Soda*, (cit. n. 13), pp. 1–13.

Figure 2. Yungli Soda Manufacturing Company. From Lin, Factory Workers in Tangku.

soda industry, designing and purchasing equipment, and overseeing the construction and operation of the Yungli plant. The knowledge acquired in this work formed the basis for his book *Manufacture of Soda with Special Reference to the Ammonia Process,* which was published by the American Chemical Society in 1934 and remains a classic in this field.[18]

Construction of the Yungli plant began in the spring of 1921, using equipment imported from the United States. The government continued to promote this venture, granting the company a monopoly on the manufacture of soda in the Tangku area and an exemption from tax on soda products to go with the earlier concession on salt. Encouraged by these moves, the stockholders approved additional funding to expand operations to the very large scale required for profitable soda manufacture. In March 1922 the new factory held its first experimental production run. What the experiments showed, however, was that Yungli's problems had just begun.

In its essentials, the Solvay process treats salt with ammonia and carbon dioxide, forming ammonium chloride and sodium bicarbonate. When the latter substance is heated, carbon dioxide and water are driven off, leaving a white residue of sodium carbonate, or soda ash. The ammonium chloride can be combined with lime to yield calcium chloride and ammonia; the latter is recycled. The elegance of the process derives from the facts that the most expensive substance, ammonia, is reused and the waste product, calcium chloride, is innocuous. The technological requirements of the system, however, are high. Large machines made of

[18] On Hou Tê-pang, see Sung Tzu-ch'êng, "Hou Tê-pang ch'êng-kung chih lu" (Hou Tê-pang's road of success), *Chung-kuo k'o-chi shih-liao,* May 1980, *1*:26–39; and Boorman, *Biographical Dictionary* (cit. n. 11), Vol. II, p. 84.

special alloys are needed to withstand the effect of highly corrosive materials under high temperature and pressure. The process tolerates no interruption, and the flow rates of liquids and gases must be precisely controlled. Enormous quantities of raw materials—salt, limestone, coal, and coke—as well as finished products must be transported, regularly and rapidly, into and out of the plant. Because of the continuity and automatic control of the operation, however, one well-trained operator and a number of manual laborers can attend to an entire plant.[19]

When introduced into China, this procedure met with two problems. First, the Yungli plant used sea salt, which, while cheaper, contained more impurities than the rock salt or subterranean brine used in Solvay factories in the West. More precisely, sea brine contains magnesium and calcium salts, which form a sticky "mud" that clogs the system. Hou Tê-pang's first achievement was to develop a method of treating the sea brine with lime and soda to convert these impurities to the corresponding sodium salts, which could then be used to produce more soda. Hou showed that even though some soda was consumed in the refining process, this method was more economical than the established technique of evaporating the seawater and separating the salts by physical means. The second problem arose from the fact that, lacking a supply of crude ammonia, Yungli engineers had substituted ammonium sulfate, which caused the iron on the inside walls of the vats to pollute the soda, turning it red. Hou's solution was to add sodium sulfate, which reacted to form a protective crust of iron sulfate on the surface of the vats, resulting in the production of snow-white crystals.[20]

Investigation into these problems was undertaken at the Golden Sea Research Institute of Chemical Industry. This institute, established in 1922 by the Chiu-ta and Yungli companies, was beholden to its founders but charged with conducting research that would benefit Chinese industry as a whole. By the late 1920s the institute had a staff of twenty to thirty professional researchers, all trained abroad, engaged in study of a wide range of industrial problems, many of them far removed from the manufacture of soda. The institute was the first privately endowed facility of its kind in China. While the success of its program is difficult to judge, this initiative by Chinese industrialists served as a model for government research organizations set up after 1928.[21]

With the solution of these technical problems, regular production began in 1924. Yungli was the first factory in the Far East to manufacture soda by the Solvay process. In 1926, its Red Triangle brand won a gold medal at the International Products Exhibition in Philadelphia. Production rose to 14,000 tons in 1927 and to over 50,000 tons in 1937. In 1931, exports from China, primarily to Japan,

[19] Hou Tê-pang, *Manufacture of Soda* (cit. n. 13), pp. 403, 431, 516.

[20] *Ibid.*, pp. 46–69; Ou-yang I, "P'ing-tung k'ao-ch'a-chi" (cit. n. 12), p. 103; Sung Tzu-ch'êng, "Hou Tê-pang" (cit. n. 18), pp. 30–31.

[21] See Ou-yang I, "P'ing-tung k'ao-ch'a-chi," p. 91; Lu Pin, "Huang-hai hua-hsüeh kung-yeh yen-chiu-shê" (The Golden Sea Research Institute of Chemical Industry), *Chung-kuo k'o-chi shih-liao*, Sept. 1981, *1*:56–60; Ch'ai Ching-hsü, "Chin Ku T'ang-shan nan-Man kung-yeh ts'an-kuan pao-kao" (Report on an inspection of the industry of Tientsin, Tangku, Tangshan, and Southern Manchuria), *Hua-hsüeh kung-yeh*, May 1930, *5*(2):92–145, on p. 111; Tsêng Chao-lün, "Êrh-shih-nien-lai Chung-kuo hua-hsüeh chih chin-chan" (Development of Chinese chemistry during the past twenty years), *K'o-hsüeh* (Science), Oct. 1935, *19*(10):1514–1542, on p. 1523; Hsüeh-wu Sun, "The Hwang-hai (Golden Sea) Research Institute of Chemical Industry," *Science and Technology in China*, Aug. 1948, *1*(4):69–70.

exceeded 7,000 tons. Yungli was a technical and financial success, paying handsome dividends to its stockholders and favorably affecting China's balance of trade.[22]

Wu Yün-ch'u

While Fan Hsü-tung was starting to make soda in north China, another captain of the chemical industry, Wu Yün-ch'u, was building his base in the south. Wu was born in 1890 to a poor household in a village outside Shanghai. He attended the local school for a brief period and in 1905, the year the examination system was abolished, entered a training program attached to the Kiangnan arsenal, where he was introduced to foreign languages and science, primarily chemistry. After completing the four-year course, he worked as a chemical technician, first at Kiangnan and later at the Hanyang arsenal, where he rose to head the chemical and powder plant. While still at Hanyang, Wu became aware of a shortage of the chemicals required to make matches caused by the disruption of foreign supply brought on by the war in Europe. In 1918, with 5,000 yuan of his own money, he set up China's first factory for the manufacture of match-making materials (potassium chlorate). When the enterprise prospered, Wu resigned from the arsenal and went to Shanghai to make his fortune. In close touch with the match business, he next took note of the need for glue to fasten combustible materials to the stick; in 1921, with capital raised from Shanghai match merchants, Wu opened his second business.[23]

In the early 1920s Shanghai was being transformed by fashions and products from abroad. Among these was a new condiment, monosodium glutamate, or MSG, whose popularity had penetrated even the bastion of Chinese cuisine. The meatlike taste of MSG was first noted by the Japanese chemist Kikunae Ikeda in the course of his study of *Laminaria japonica,* the Japanese seaweed used as a flavoring. Ikeda and a colleague patented the manufacture of MSG in 1908, and its popularity as a condiment spread throughout East Asia, particularly to China, where, by the mid-1920s, consumption exceeded $1 million annually.

Wu Yün-ch'u recognized the potential of this new industry and undertook to master the method of manufacture. In 1922, he raised 50,000 yuan, primarily from the Kincheng Bank, to establish the T'ien-ch'u Monosodium Glutamate Factory. Wu applied for a Chinese patent on this process, but the Japanese protested what they took to be a violation of their legal rights, and it is not clear whether the patent was in fact granted. It is certain, however, that T'ien-ch'u began making the seasoning and that by 1928 the value of domestic production exceeded that of imports. Because it required special knowledge and skill, the manufacture of MSG did not spread beyond Shanghai, but it served during the 1930s as an important catalyst for the chemical and food industries of that city.[24]

[22] On the gold medal, see Sung Tzu-ch'êng, "Hou Tê-pang" (cit. n. 18), p. 31; on production, export, and profits, see *Shina kōgyō* (cit. n. 6), pp. 14–16, 24, 81, 100.

[23] On Wu, see Ch'ên Chên and Yao Lo, eds., *Kung-yeh-shih tsŭ-liao* (cit. n. 11), pp. 521–529; on match and glue factories, see Ch'ên T'ao-shêng, "Hu-Han k'ao-ch'a-chi" (cit. n. 7), p. 242.

[24] Wang Shih-mo, "Tan-pai-chih chung ti ku-suan yü ku-suan-na t'iao-wei-fên" (Glutamic acid and monosodium glutamate seasoning in proteins), *K'o-hsüeh,* July 1933, *17*(7):1018–1048; and Tsêng Chao-lün and Hu Mei, "Gluten Hydrolysis and Preparation of d-Glutamic Acid Hydrochloride," *Journal of the Chinese Chemical Society,* June 1935, *3*(2):154–172.

At the time, MSG was made from wheat. Wheat flour is the source of starch, which was extracted by spinning mills and used to stiffen yarn or cloth. The sticky residue, "crude gluten," is the starting material for the manufacture of MSG. Separation of gluten from starch was a laborious process, carried out by washing the starch in running water and working the liquid with a bamboo pole or trampling underfoot. The T'ien-ch'u factory experimented with a kneading machine, but it never worked properly and was abandoned. Once separated, the gluten was treated with hydrochloric acid and soda to form the salt, MSG.

Development of this industry in China depended in large part on the supply of raw materials. The only source of crude gluten was spinning factories, whose limited production led some experts to conclude that an adequate supply of gluten would have to await the development of other starch-consuming industries, such as glucose and alcohol. They may have been right; production of both MSG and ethyl alcohol grew rapidly during the early 1930s, although I have found no evidence of a causative link. The second key substance in the manufacture of MSG, hydrochloric acid, was imported from Japan. Primarily to displace the Japanese as suppliers of his MSG plant, in 1928 Wu established the next element of his chemical complex, a factory to make hydrochloric acid.[25]

CHEMICAL INDUSTRY DURING THE NANKING DECADE, 1928–1937

After 1928 the pace of change in the Chinese chemical industry quickened. In part, this was due to two economic factors: the accumulated growth of those industries that consume chemical inputs and the creation of demand large enough to support domestic production of acids, sodas, and other intermediate products. Yet in many ways the 1930s were difficult years for the Chinese economy—the loss of Manchuria to the Japanese denied China one of its most promising centers of development, and the world depression, while hitting China later and less severely than other countries, nonetheless took its toll. In sum, the rate of industrial growth during the decade 1928–1937 was probably no greater than that during the warlord period preceding it, which suggests that there were other reasons for the introduction of new types of equipment and methods of manufacture. Among these was politics. The unification of China under the Nationalist government, the creation of a sense of security and direction, and the imposition of priorities that favored key sectors of the economy, including chemicals, all contributed to a greater confidence in the future and a willingness to try out new, sometimes expensive, techniques. In the chemical sector, more innovations were introduced and more new enterprises established during the Nanking Decade than in the entire century preceding it.[26]

Wu Yün-ch'u's Chemical Empire

These trends were evident in the decision by Wu Yün-ch'u to begin making hydrochloric acid, using the most current method. The simplest and cheapest

[25] See *China Industrial Handbooks: Kiangsu* (Shanghai: Ministry of Industry, 1933), pp. 655–656.

[26] For figures on the textile industry's accumulated growth, see Thomas Rawski, *China's Transition to Industrialism* (Ann Arbor: Univ. Michigan Press, 1980), p. 16; on the rate of industrial growth, see Lloyd Eastman, *The Abortive Revolution: China under Nationalist Rule, 1927–37* (Cambridge, Mass.: Harvard Univ. Press, 1974), pp. 239, 364 n. 172.

way to make hydrochloric acid is by the reaction between sulfuric acid and salt. At the time, however, the Chinese produced no sulfuric acid for the commercial market, so Wu opted for a more direct if unproven (in China) technique: electrolysis. In this process, a strong electric current creates opposite charges on electrodes submerged in a specially designed cell filled with sodium chloride solution. Positively charged sodium ions gather at the negative pole, combining with water to form sodium hydroxide (caustic soda) and hydrogen gas. Negatively charged chlorine ions gather at the positive pole to form chlorine gas, which can be used to make liquid chlorine, bleaching powder (chloride of lime), or hydrochloric acid. Electrolysis was developed in the United States in the 1890s and assumed a growing commercial importance after the turn of the century. It was first tried in China during World War I by Chinese investors working with a German technician, but the attempt failed owing to the high cost of electricity, the major expense in operating factories of this type.[27]

The T'ien-yüan Electrochemical Company was founded in 1928, with 200,000 yuan raised from T'ien-ch'u stockholders and an exemption from tax on the principal raw material, refined salt. In the fall of that year Wu learned that a French firm located in Haiphong had failed and was planning to sell its electrolysis plant. He went to Haiphong to inspect the equipment, found it in good condition, and bought the entire lot, including 120 electrolytic cells for which he paid only one third of the market price. These were Allen-Moore diaphragm cells, which were somewhat less efficient than the competing mercury cells, but were cheaper and required less energy, the principal considerations for Chinese manufacturers at this time. The equipment was shipped to Shanghai, a site chosen because of its proximity to the T'ien-ch'u plant, which would consume most of the acid, and the existence of a reliable supply of electricity, unavailable in most other parts of China. The salt came from nearby Chekiang. Like Wu's other plants, T'ien-yüan was an immediate success. By 1937, its capital investment had increased to one million yuan, three hundred cells were in constant operation, and annual production of hydrochloric acid reached 1,500 tons. The plant also made caustic soda and bleaching powder, which were sold to soap, paper, and dye factories in Shanghai.[28]

The electrolysis of salt is one of several chemical industries that make many distinct, even unrelated, products by a single, flexible method. The great advantage of such industries is that the outputs can be adjusted to meet changing market and other conditions. Thus the T'ien-yüan factory was created to manufacture hydrochloric acid, but its by-products—bleaching powder, caustic soda, and eventually liquid chlorine—assumed greater importance with the passage of

[27] On electrolysis, see D. W. F. Hardie, *Electrolytic Manufacture of Chemicals from Salt* (London: Oxford Univ. Press, 1959), pp. 60–65; on the World War I venture, see Wu Ch'êng-lo, "Hua-hsüeh kung-yeh wên-t'i" (cit. n. 9), p. 8.

[28] On T'ien-yüan, see Ch'ên Chên and Yao Lo, eds., *Kung-yeh-shih tsŭ-liao* (cit. n. 11), pp. 522–526; Li Ch'iao-p'ing, *Chung-kuo hua-hsüeh shih* (History of Chinese chemistry) (Taipei: T'aiwan shang-wu yin-shu-kuan, 1976), Vol. II, pp. 374, 416; and Yü Jên-chün, "Wo-kuo shih-yen tien-chieh kung-yeh chih ching-chi kuan" (Economic outlook for our country's salt electrolysis industry), *Hua-hsüeh kung-yeh*, Apr. 1947, *19*(1–2):4–9, on pp. 4–6. On electrolytic cells, see W. L. Badger and E. M. Baker, *Inorganic Chemical Technology* (New York: McGraw-Hill, 1941), pp. 150–170. On salt, see *China Industrial Handbooks* (cit. n. 25), p. 659. For investment and production figures, see *Shina kōgyō* (cit. n. 6), p. 150.

time. Caustic soda, in particular, was vital to the development of chemical and allied industries in China, as elsewhere.

There was little demand for caustic soda until the late nineteenth century, when high-speed presses began to consume mountains of pulp paper, made by soaking wood fibers in caustic soda, and textile factories began to treat cotton cloth by the Mercer process, which also uses this chemical. Originally, caustic soda had been made from soda ash by a chemical method that relied on the reactions among lime, water, and sodium carbonate. This simple and efficient technique was first used in China during World War I to caustify natural soda. Large-scale production began in 1932, when the Yungli company set up a factory on the Tangku site, employing the same method. With an output of 4,000 tons per year, Yungli was the leading producer of caustic soda in China. By the 1930s, the Chinese recognized the potential of electrolysis. Besides T'ien-yüan, the Kwangtung Provincial Electrochemical Factory, a government enterprise, opened in 1935, using Vorce-type diaphragm cells designed and built in the United States. Production at this plant reached six tons of caustic soda, and similar amounts of bleaching powder and hydrochloric acid, per day.[29]

In addition to caustic and ash, the Chinese manufactured two other soda products: sodium sulfide, which is made from soda ash or from a common natural material, saltcake (sodium sulfate) and used to make soap, dyes, and paper pulp; and sodium silicate (water glass), which is made by fusing sand and soda ash and used in the bleaching and sizing of textiles and paper. The major producer of these intermediates was the Pohai Chemical Works, founded in Tangku in 1926, by three engineers from the nearby Chiu-ta salt refinery, two of whom had studied chemistry in Tokyo and Berlin. By the mid-1930s this plant produced 1,600 tons of sodium sulfide and 3,600 tons of silicate per year. Beginning in 1935 Pohai also manufactured its own soda ash, 5,000 tons annually, all of which was consumed in the production of sodium sulfide.[30]

Wu Yün-ch'u exhibited many of the traits of an industrial pioneer: he learned the business from the bottom up, he was directly involved in the management of all his factories, and he recognized opportunities and pursued them boldly. In addition to the enterprises already discussed, Wu went on to build a nitric acid factory, which made use of surplus hydrogen gas from the electrolysis plant, and a chemical porcelain factory, a spin-off of an earlier in-house operation. Like Fan Hsü-tung, he formed his own research and development unit, the Chinese Industrial Chemical Research Institute. Wu was instrumental in establishing the Chinese Society of Chemical Industry and created foundations to support students of chemical engineering and public charities. During the war he moved his factories to the rear areas and helped carry on the struggle against Japan. He died in Shanghai in 1953.[31]

[29] On the history of caustic soda, see Haber, *Chemical Industry* (cit. n. 7), pp. 95–98. On natural soda, see Kuo Pên-lan, "Chang-chia-k'ou chih liang ta hua-hsüeh kung yeh" (cit. n. 14), pp. 137–139; and on Yungli, see Li Ch'iao-p'ing, *Chung-kuo hua-hsüeh shih* (cit. n. 28), p. 374. On the T'ien-yüan and Kwangtung caustic soda factories, see *ibid.*, pp. 374, 416; *Shina kōgyō*, pp. 68–70, 150; "Kuo-nei kung-yeh" (Chinese industry), *Hua-hsüeh kung-ch'êng* (Journal of Chemical Engineering, China) (Tientsin, Chinese Institute of Chemical Engineers, 1934–1949), Mar. 1936, *3*(1):74–77, on p. 74; Wu Ch'êng-lo, "Hua-hsüeh kung-yeh wên-t'i" (cit. n. 9), p. 8; and Yü Jên-chün, "Tien-chieh kung-yeh" (cit. n. 28), pp. 4–9.

[30] See *Shina kōgyō* (cit. n. 6), pp. 31–32.

[31] For an obituary of Wu, see *Hua-hsüeh shih-chieh* (Chemical World), Nov. 1953, *8(11)*.

Acid Manufactures

Manufacture of sulfuric acid, the most important of all industrial chemicals, also illustrates the rapid changes in this field during the Nanking Decade. Prior to 1933 production of acid by the Chinese was limited to government agencies and was solely for the purpose of making explosives. There was some evidence of technological progress; by the early 1920s the Hanyang arsenal had installed Gay-Lussac and Glover towers, which served to recover nitrogen oxides, increase the efficiency of the lead chambers, and clean up the air. However, the Tehchow arsenal, which may have been more representative of the industry, had no such refinements and simply burnt sulfur and niter, feeding the gases directly into lead chambers, in a small and primitive system. Sulfuric acid was combined with potassium or sodium nitrate to produce nitric acid; both were used to make guncotton.[32]

One foreign concern attempted to manufacture acids in China, albeit with limited success. Major Brothers, later called the Kiangsu Chemical Works, was founded in 1901 by British investors in Shanghai to supply local factories with sulfuric acid, along with lesser amounts of hydrochloric and nitric acids. Owing to the high cost and unreliable supply of raw materials, however, this enterprise foundered and was sold in 1922 to another group of foreigners, who experienced similar difficulties. As late as 1933, the total output of Major Brothers was less than 50 tons per year. By 1936, after the introduction of new equipment and imported sulfur, production increased to 2,700 tons, but by this time there was competition from Chinese manufacturers.[33]

The largest Chinese producer of sulfuric acid was the K'ai-ch'êng Acid Company. Founded in Shanghai in 1931 with an initial investment of 500,000 yuan, K'ai-ch'êng also suffered from the high cost and low quality of Chinese sulfur-bearing ores and was unable to begin production until 1933. This factory, under a Chinese manager, had three lead chambers, featured Gay-Lussac and Glover towers, and burned pyrites from neighboring Chekiang Province. It had a capacity of 4,500 tons per year, although peak production was only about 3,000 tons. Over half the output was sold to arsenals, while the rest went to factories producing textiles, dyes, enamelware, soda water, plastics, and soap.[34]

In the same year K'ai-ch'êng began operation in Shanghai, the largest plant in north China, the Li-chung Acid Company, opened in Tientsin. Li-chung was founded with an initial investment of 200,000 yuan by a group of men with connections to several provincial governments in the region. The plant, which burned pyrites from Honan and Shensi in lead chambers, was designed by engineers from the Nankai University Institute of Applied Chemistry in Tientsin. It

[32] On Hanyang, see Ch'ên T'ao-shêng, "Hu-Han k'ao-ch'a-chi" (cit. n. 7), pp. 234–240. On Tehchow, see Wei T'ing-ying, "Chi-nan, Ch'ing-tao, Tê-chou, T'ang-shan, T'ang-ku" (cit. n. 7), p. 212. On towers, see Haber, *Chemical Industry* (cit. n. 7), pp. 102–108; and F. Sherwood Taylor, *A History of Industrial Chemistry* (New York: Abelard-Schuman, 1957), pp. 189–190.

[33] See Wu Ch'êng-lo, "Hua-hsüeh kung-yeh wên-t'i" (cit. n. 9), p. 5; *China Industrial Handbooks* (cit. n. 25), pp. 655–657; and *Shina kōgyō* (cit. n. 6), pp. 123–124, 152.

[34] On K'ai-ch'êng, see Wu Ch'êng-lo, "Hua-hsüeh kung-yeh wên-t'i" (cit. n. 9), p. 5; and *Shina kōgyō* (cit. n. 6), p. 148. On technology, see Ting Szŭ-hsien, "Chien-shê kuo-fang hua-hsüeh kung-yeh chih wo-chien" (My views on establishing a chemical industry of national defense), *Hua-hsüeh kung-ch'êng*, June 1935, *2*(1):74–83, on p. 82; on pyrites, see *China Industrial Handbooks*, pp. 658–659; on the market for acid, see *ibid.*, pp. 659–661; and on production, see "Kuo-nei kung-yeh" (cit. n. 29), p. 75.

began operation in 1934 and reached an annual output of 1,200 tons, all of which was marketed in north China.[35]

Kwangtung and Kwangsi provinces were the center of this industry in south China. Canton, capital of Kwangtung, had long served as China's gateway to Southeast Asia and, more recently, as the marketplace for goods and ideas introduced to this region from the West. Within China, this was one area that prized innovation and the entrepreneurial spirit. In contrast to those in the other major centers, Shanghai and Tientsin, however, chemical industries in the south came under official control. In 1927, the government of Kwangsi, using 600,000 yuan from the army budget and with the assistance of German technicians, set up a lead chamber plant at Wuchow to supply acids for the manufacture of gunpowder. This operation failed and was reorganized, with the injection of new funds from Kwangtung Province, as the Liang-Kwang Provincial Sulfuric Acid Factory, under a Chinese director. Meanwhile, in 1933, the government of Kwangtung established a second enterprise, the Kwangtung Provincial Sulfuric Acid Factory, in Canton. By 1936, the capacity of these two plants reached 7,500 tons, although actual production was never that high. The entire output went to supply provincial gunpowder and fertilizer factories.[36]

The Kwangtung plant was built around a new process, the "contact" method, which had been developed in Germany at the end of the nineteenth century to supply the synthetic dye industry with acids of greater concentration than those produced by the chamber method. The name derives from the fact that the key step in the synthesis of sulfuric acid, oxidation of sulfur dioxide to trioxide, is effected by bringing the gas into contact with a metallic catalyst, first platinum and later vanadium. Commercial production of sulfuric acid by this method began around 1890 and assumed growing importance, primarily in Germany, after the turn of the century. Since concentrated acid was more effective in the manufacture of high explosives, all the major powers built contact plants during World War I. The contact process placed greater demands on the manufacturer, for the metallic catalyst is easily contaminated and requires the use of pure sulfur and careful controls. It also offers several advantages over the chamber method: the plant occupies less space and requires no towers or other special buildings, there is no need to construct and maintain massive lead chambers, and the product is more concentrated and therefore more economical and easier to transport. The first factory in China to make sulfuric acid by the contact method was established in 1927 at the government arsenal in Liaoning Province. During the next decade, the arsenals at Tehchow, Chengtu, Taiyuan, and Kung-hsien also adopted this technique. The Kwangtung Acid Factory introduced American equipment, using a vanadium catalyst, and burned imported sulfur. The first contact plant for commercial production was built in 1936 as a part of the Yungli ammonium sulfate complex, the last and greatest of China's prewar chemical enterprises.[37]

35 See *Shina kōgyō* (cit. n. 6), pp. 143–144.

36 On Liang-Kwang, see *ibid.*,p. 155; on Kwangtung, see "Kuo-nei kung-yeh" (cit. n. 29), p. 74. On both plants, see Wu Ch'êng-lo, "Hua-hsüeh kung-yeh wên-t'i" (cit. n. 9), p. 5; Fan Ching-p'ing, "Kuo-ch'an liu-suan chih fen-hsi" (Analysis of sulfuric acid produced in China), *Kung-yeh chung-hsin* (Industrial Center) (Nanking, National Bureau of Industrial Research, 1932–1940), Dec. 1936, *5*(12):578–582; and Shên Tsêng-tso, "Liu-suan kung-yeh chi ch'i hsin ch'ü-shih" (The sulfuric acid industry and its new direction), *ibid.*, Oct. 1948, *12*(1):10–13, on p. 10.

37 On the history of the contact method, see Haber, *Chemical Industry* (cit. n. 7), pp. 102–108;

Nitrogenous Fertilizers

In addition to acids and sodas, the nitrogen-bearing compounds are among the most important industrial chemicals. Plants use nitrogen to make amino acids, which form proteins and protoplasm, the foundation of the food chain and the stuff of life itself. Nitrogenous fertilizers, such as ammonium sulfate, return this element to the soil, making possible the continuous high yields of modern agriculture. But man has also used nitrogen in less constructive ways, for it is the prime component of nitric acid and, hence, the high explosives: nitroglycerin, nitrocellulose, and trinitrotoluene (TNT). One of the most abundant elements in nature, nitrogen is relatively inactive and must be "fixed," or combined with other elements, before it is available for some other use. Bacteria perform this function in nature, preparing nitrogen in the soil for digestion by plants. One of the most important innovations of the modern chemical industry has been to fix nitrogen by synthetic means.

Prior to World War I the most abundant source of usable (fixed) nitrogen was Chile saltpeter (sodium nitrate), so named because enormous natural deposits were found in that country, which exported the substance all over the world. Following the outbreak of war, the blockade of continental Europe denied to Germany its supply of foreign nitrates for the manufacture of fertilizers, explosives, and other necessities. Building on innovations of the early 1900s, German chemists developed techniques for the mass production of synthetic ammonia (Haber-Bosch process) and, from ammonia, nitric acid (Ostwald process), which freed Germany from dependence on Chile saltpeter and gave it a sizable lead in the manufacture of munitions during the war.[38]

The lesson in chemistry administered by the Great War was firmly planted in the minds of Western statesmen and industrialists. During the 1920s Britain, France, Germany, the United States, and other countries erected synthetic ammonia factories and began to manufacture nitrogenous fertilizer in great abundance, knowing that the facilities could be converted to produce explosives if war should recur. By 1931 world production of ammonium sulfate neared two million tons, while consumption was just over half that amount. The great strategic importance of fixed nitrogen led to the expansion of this industry beyond all economic reason.[39]

Although Chinese military planners also recognized the strategic benefits of nitrogen fixation, the needs of the agricultural sector brought the matter to wider attention. After the mid-1920s China's imports of grain and flour mounted, finally exceeding 2.6 million tons and a cost of $62 million, about one eighth of all imports, in 1931. One way to stem the drain of cash for the purchase of food was to increase yields of rice and wheat, a strategy calling for greater inputs of chemi-

Taylor, *History of Industrial Chemistry* (cit. n. 32), pp. 424–426; and Aaron J. Ihde, *The Development of Modern Chemistry* (New York: Harper & Row, 1964), p. 675. On the arsenals, see Li Ch'iao-p'ing, *Chung-kuo hua-hsüeh shih* (cit. n. 28), p. 370; and Wu Ch'êng-lo, "Hua-hsüeh kung-yeh wên-t'i" (cit. n. 9), p. 5; on Kwangtung, see Ch'ên Tê-yüan, "Liu-suan yü hsiao-suan chih-tsao fang-fa chih ko-ming" (Revolution in the method of manufacture of sulfuric and nitric acids), *Hua-hsüeh kung-yeh*, Jan. 1937, *12*(1):2–10, on p. 7; and "Kuo-nei kung-yeh" (cit. n. 29), p. 74.

[38] See Ihde, *Development of Modern Chemistry* (cit. n. 37), pp. 678–680.

[39] In 1931, world ammonium sulfate production was 1.9 and consumption 1.1 million metric tons; Hsü Shan-hsiang, "Chung-kuo jên-tsao fei-liao chih hsien-tsai chi chiang-lai" (The present and future of China's artificial fertilizer), *Hua-hsüeh kung-yeh*, Jan. 1933, *8*(1):1–20, on p. 16.

cal fertilizers. Japan, with a similar type of agriculture, one fifth the population, and one tenth the arable land, consumed more than five times as much ammonium sulfate as China. Until this time, chemical fertilizers had been used primarily in south China, where the proximity to foreign markets and the high price of agricultural goods encouraged such investments. The spread of this practice to north China and greater application of fertilizer throughout the country seemed to some observers a reasonable course to follow.[40]

Given that China needed more fertilizer, there remained the question of where it should come from. During the latter half of the 1920s, China's imports of ammonium sulfate increased by 50 percent per year, reaching 190,000 tons and a cost of more than $6 million in 1930. Some Chinese pointed to the world glut of this chemical and argued that China should remain a buyer. But current trends ran in the opposite direction. Joining the major producers in the West, Japan opened additional plants, while the first Soviet Five-Year Plan also called for heavy investment in this industry. To many Chinese, the argument seemed compelling: in the short run, manufacturing ammonium sulfate in China would raise agricultural yields and stem the outflow of cash for grain and fertilizer; in case of war, these plants could be converted to produce nitric acid for the munitions industry.[41]

In 1931 the Ministry of Industry began to explore the problem of building nitrogen fixation and ammonium sulfate plants in China. The Chinese first approached British and German firms, but their terms for a joint venture were too stiff, so in 1934 Nanking turned to Fan Hsü-tung. Fan accepted a government loan of 5.5 million yuan at 7 percent for five years and changed the name of his corporation to the Yungli Chemical Industry Company to reflect its broader scope. He purchased 275 acres of land at Hsiehchiatien, on the Yangtze River near Nanking, as the site for the new plant; this spot was chosen because of the need to import large, bulky equipment, including a one-hundred-ton ammonia synthesizer. Meanwhile, Hou Tê-pang was dispatched to the United States, where he bought equipment and signed a contract with the American Cyanamid Company to supervise construction. By the end of 1936 four separate factories were in place: one each for synthetic ammonia, sulfuric acid, nitric acid, and ammonium sulfate. Production began in February of the following year.[42]

[40] On grain and flour imports, see *ibid.*, p. 2; on Japan, see *ibid.*, pp. 7, 19. *Shina kōgyō* (cit. n. 6), pp. 166–167, shows that during the period 1926–1935, of all ammonium sulfate in China, 69 percent was consumed in south China, 25 percent in central China, and 6 percent in north China. Hsü Shan-hsiang was one of those who advocated the manufacture and greater application of ammonium sulfate in China.

[41] On the imports, see *Shina kōgyō*, p. 169; and Hsü Shan-hsiang, "Chung-kuo jên-tsao fei-liao chih hsien-tsai chi chiang-lai" (cit. n. 39), p. 4; on Japan and the Soviet Union, see *ibid.*, p. 19; on reasons for production, see *ibid.;* and Ho Shang-p'ing, "Tan-chih hua-hsüeh fei-liao yü wo-kuo nung-yeh" (Nitrogenous chemical fertilizer and our country's agriculture), *Hua-hsüeh kung-yeh*, Jan. 1933, *8*(1):21–30.

[42] See "Yung-li liu-suan-ya-ch'ang ch'êng-kung chih i-i" (Significance of the success of the Yungli ammonium sulfate factory), *Hua-hsüeh kung-ch'êng*, June 1937, *4*(2):111–112; "Yung-li hua-hsüeh kung-yeh kung-szŭ liu-suan-ya-ch'ang ch'êng-li ching-kuo chi ch'i kai-k'uang" (The process of establishment and current status of the Yungli Chemical Industry Company ammonium sulfate factory), *ibid.*, pp. 183–195; Wu Ch'êng-lo, "Hua-hsüeh kung-yeh wên-t'i" (cit. n. 9), p. 9; Wu Ch'êng-lo, "San-shih-nien-lai Chung-kuo chih suan-chien hua-hsüeh kung-ch'êng" (China's acid and soda chemical engineering during the past thirty years), in *San-shih-nien-lai chih Chung-kuo kung-ch'êng* (Chinese engineering during the past thirty years), ed. Chou K'ai-ch'ing, 2 vols. (Taiwan: Hua-wên shu-

In the Haber process, employed at Hsiehchiatien, pure hydrogen and nitrogen gases were combined under high temperature and pressure to form ammonia. The hydrogen was produced in a water gas generator, the nitrogen by heating coke. The ammonia, condensed to liquid form, was combined with sulfuric acid, made by the contact method, to produce ammonium sulfate. Enormous sophisticated machines moved great mounds of raw materials in a continuous process, all on a par with the international standards for this industry. The Yungli plant had a capacity of 150 tons of ammonium sulfate per day, or 54,000 tons per year, an amount equal to one third of China's total imports at the time.

The Hsiehchiatien complex was the most modern and complete chemical facility in China and demonstrates the high level achieved by this industry prior to World War II. Its key pieces of equipment were imported, but much of the rest was manufactured in the company's own foundry and workshops. Only three foreign advisers took part in construction of the plant; none was needed to supervise its operation. The entire work force was Chinese and included more than eighty college graduates, twenty of whom had received higher engineering degrees from foreign universities; this factory had one of the greatest concentrations of trained manpower in China. The enterprise was financed by low-interest government and private loans guaranteed by Yungli's assets at Tangku, which kept the cost of construction low and enabled the company to obtain the newest and best equipment. Separate factories were planned for sodium nitrate, ammonium nitrate, and nitro-chalk, while Yungli researchers worked on refining sulfur and coke.

Hsiehchiatien, by far the largest synthetic ammonia facility in China proper, was preceded by two smaller plants in Shanghai and Canton. The first of these was the T'ien-li Nitrogen Gas Company, established in Shanghai in 1936 by Wu Yün-ch'u with an initial investment of one million yuan and secondhand nitrogen fixation equipment purchased from Du Pont corporation. Wu entered this field because it offered a profitable outlet for the hydrogen gas produced in abundance as a by-product of his electrolysis plant. Since it was known that Yungli would manufacture ammonium sulfate, T'ien-li specialized in nitric acid, using the Ostwald process and equipment purchased from France. This factory produced nearly 2,000 tons of nitric acid per year, along with lesser amounts of liquid ammonia and ammonium nitrate. The Yungli complex included a nitric acid plant that used the same technology on a similar scale.[43]

Further south, the Kwangtung Provincial Fertilizer Factory opened in 1935 to meet that region's growing demand for chemical nutrients. This plant made its own ammonia, which was combined with sulfuric acid from the provincial acid factory to produce forty tons of ammonium sulfate per day. Two other departments manufactured phosphorus and potassium fertilizers, which were consumed in south China in lesser amounts but became increasingly important as the repeated application of nitrogen left the soil depleted of these other minerals.[44]

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chü, n.d.), Vol. I, pp. 15–16; and Jung-chao Liu, *China's Fertilizer Economy* (Chicago: Aldine, 1970), pp. 10, 129.

[43] On T'ien-li, see Wu Ch'êng-lo, "Hua-hsüeh kung-yeh wên-t'i" (cit. n. 9), p. 9; "Kuo-nei kung-yeh" (cit. n. 29), p. 74; and Hsi Yeh, "T'ien-li tan-ch'i-ch'ang kai-k'uang" (Status of the T'ien-li nitrogen gas factory), *Hua-hsüeh shih-chieh* (Chemical World), June 1951, *6*(2):10ff., on p. 10. For production figures, see *Shina kōgyō* (cit. n. 6), p. 153.

[44] See "Kuo-nei kung-yeh" (cit. n. 29), p. 74; Wu Ch'êng-lo, "Hua-hsüeh kung-yeh wên-t'i" (cit. n.

Organic Chemicals

Less successful but no less interesting was the Chinese experience with the manufacture of organic chemicals. Organic, or carbon, compounds make up many useful products, including drugs, dyes, explosives, plastics, flavorings, colorings, and perfumes. The Chinese were no strangers to this field, for they had pioneered a great pharmacopoeia of plant and animal materials and founded several industries, such as ink, paper, wines, and sauces, that rested on the chemical transformation of organic substances. In the modern era, however, they had to learn these skills, and the reasons why they work, all over again. In most product lines the Chinese failed miserably. In one, however, they achieved notable success. This was alcohol.

Alcohol. Ethyl alcohol, or ethanol, is one of the most common organic solvents and is used in the manufacture of countless products. Ethanol is produced by the action of yeast enzymes on sugars, which are converted by fermentation to carbon dioxide and alcohol. The sugar may be obtained directly from molasses, the waste product of a sugar refinery, or indirectly from starches, such as grain, corn, or potatoes, that have been ground up and saccharified by any of several processes. In either case, the concentration of alcohol obtained from fermentation is around 10 percent; distillation removes excess water and raises the concentration to the standard industrial grade of 95 percent or above. The techniques of this industry were introduced into China by Europeans, who monopolized the manufacture of ethanol in that country prior to 1920.

The first Chinese enterprise in this field was the P'u-i Sugar Factory of Tsinan, which in 1922 began to make alcohol from molasses at the rate of 1,200 gallons per day. This factory closed following the Tsinan Incident of 1927, and within two years imports of ethanol exceeded six million gallons. With recognition of the importance of this industry, the China Alcohol Factory was established in Shanghai in 1934 as a joint venture between the government and an overseas Chinese with large sugarcane holdings in Java. The factory had the most modern British (Blair) equipment and a daily capacity of 7,000 gallons. Another major producer was the Kwangtung Provincial Sugar Factory, whose two alcohol plants had a capacity of 5,400 gallons per day. The Hsien-yang Alcohol Factory, founded in Shensi Province in 1936, employed a German technician and German (Haig) equipment to reach a daily capacity of 1,200 gallons of anhydrous alcohol; it was the only facility of its type in China. By 1937 there were nine major alcohol distilleries under Chinese management, with a total annual capacity of 7.2 million gallons. Much of the equipment was imported, but the technicians, with the exception of those at Hsien-yang, were all Chinese. As a result of their efforts, China's imports of ethanol fell by more than 95 percent, to less than 200,000 gallons, in 1936.[45]

9), p. 10; and Chou Ch'ang-yün, "T'u-jang fei-liao-hsüeh" (Soil fertilization studies), in *Chung-hua min-kuo k'o-hsüeh chih* (Record of science in the Republic of China), ed. Li Hsi-mou (Taipei: Chung-hua wên-hua ch'u-pan shih-yeh wei-yüan-hui, 1955), p. 22.

[45] On P'u-i, see Wei T'ing-ying, "Chi-nan, Ch'ing-tao, Tê-chou, T'ang-shan, T'ang-ku" (cit. n. 7), p. 207; and Ch'ên T'ao-shêng, "Chi-nan hua-hsüeh kung-yeh chih kai-k'uang" (Status of the Tsinan chemical industry), *Hua-hsüeh kung-yeh,* Jan. 1925, *3*(1):213–258, on p. 247; on later developments, see Lu Pao-yü, "San-shih-nien-lai Chung-kuo chih chiu-ching kung-yeh" (China's alcohol industry

The Chinese also made some organic acids and related chemicals. The Kiangnan Acetic Acid Company was founded in Shanghai in 1934 by Hsüeh Chi-ming, an engineer from a neighboring acid plant, who installed German equipment in a converted silk factory. This plant distilled elm wood from Szechwan Province to produce 350 tons of pure acetic acid per year, along with lesser amounts of charcoal, asphalt, and wood alcohol (methanol).[46]

Synthesis of organic compounds. As well as the successful undertakings of Chinese manufacturers, it is instructive to note those fields in which they did not excel. Most striking was the failure to develop industries that rest on the synthesis of organic materials. While a few techniques for treating organic substances—for example, fermentation—have long histories in China and other parts of the world, man's whole relationship to the carbon compounds changed during the second half of the nineteenth century, when the synthesis of chemical dyes, first in England and then in Germany, opened a broad new avenue of industrial development. Before the rise of petroleum in the 1920s, the primary source of organic substances was coal tar, a by-product in the distillation of coal to produce coke. The extraction of carbon compounds from coal and the assemblage of many useful products from these simple starting materials is one of the revolutions that has shaped the modern world.

The Chinese discovered the importance of these developments through the drug industry. In the early 1920s the International Dispensary of Shanghai, a Chinese company established in 1907 and expanded by the purchase of a competing German firm, began to produce Lysol, an antiseptic derived from coal tar. The tar was obtained from the Shanghai Gas Company, a British concern founded in 1866 to supply that city with coal gas (methane) to fire its street lamps. Shanghai Gas, the first and largest company of its kind in East Asia, manufactured methane by the dry distillation of coal and marketed a variety of by-products. Just as some Chinese began to appreciate the importance of coal tar, however, hopes for this industry were destroyed by larger economic forces.[47]

The problem lay at some remove from drugs and dyes, namely with iron. The manufacture of iron requires high temperatures, achieved by burning coke. Coke is made by the distillation of bituminous coal, the principal by-product of which is a black, sticky liquid called tar. The supply of coal tar, in large quantities and at low cost, depends primarily on the health of the parent iron industry. China is

during the past thirty years), in *Chung-kuo kung-ch'êng*, ed. Chou K'ai-ch'ing, Vol. II, pp. 1–2 (all articles in this volume are numbered individually, beginning with p. 1); and Li Ch'iao-p'ing, *Chung-kuo hua-hsüeh shih* (cit. n. 28), pp. 400–401. For trade statistics, see *China Year Book* (cit. n. 8), 1935, p. 195; 1936, p. 55; 1938, p. 67; and Li Êrh-k'ang, "Wo-kuo hua-hsüeh kung-yeh kai-k'uang chi ch'i fa-chan t'u-ching" (The current status and path of development of our country's chemical industry), *Kung-yeh chung-hsin*, Aug. 1937, *6*(7–8):268–280; Sept.–Dec. 1937, *6*(9–12):338–357, on p. 340.

[46] See "Kuo-nei kung-yeh" (cit. n. 29), p. 75; *Shina kōgyō* (cit. n. 6), p. 154; Li Êrh-k'ang, "Kung-yeh kai-k'uang" (cit. n. 45), p. 270.

[47] On Shanghai Gas, see Wu Ch'êng-lo, "Hua-hsüeh kung-yeh wên-t'i" (cit. n. 9), p. 10. For details about the International Dispensary, see *China Industrial Handbooks* (cit. n. 25), pp. 663–665; and Wu Ch'êng-lo, "Ts'ung Shang-hai hua-hsüeh kung-i chan-lan-hui kuan-ch'a Chung-kuo hua-hsüeh kung-yeh chih hsien-chuang" (Observing the present situation of the Chinese chemical industry on the basis of the Shanghai chemical handicraft exhibition), *Chung-hua hua-hsüeh kung-yeh-hui hui-chih* (Journal and Proceedings of the China Society of Chemical Industry), Jan. 1924, *2*(1):7–56, on pp. 11–12.

blessed with large deposits of iron ore and coal of all types, which have been mined for centuries in one of the world's oldest iron-making traditions. Modern machine methods were introduced in the late nineteenth century, most notably at Hanyang, where fuel and ore from neighboring provinces were assembled to make iron on a grand scale and supply the arsenal.

Unfortunately, after a promising start, the coal tar industry in China collapsed in the early 1920s. The boom came during World War I. Expansion of Chinese industry created a demand for construction materials just at the time when foreign supplies were diverted to Europe, resulting in a tenfold increase in the price of iron and steel in China during the decade 1912–1922. Mines, refineries, and smelting and coking furnaces opened throughout the country to meet current demand and in anticipation of future growth. Then came the crash. In 1922 surplus production in China and elsewhere, a downturn in the global economy, and the return of foreign suppliers to the Far East caused a sharp decline in the price of iron. The Hanyang Iron Works, the industry leader for thirty years, closed in 1924. Throughout the 1920s and 1930s China exported coal and iron ore, while importing over 90 percent of its finished iron and steel. The crash of 1922 marked the end of large-scale iron production under Chinese control until after 1949.[48]

No iron production meant no coke, and thus no ready supply of cheap tar on which to build an organic chemical industry. The Chinese did keep one coke and tar plant in operation, and this remained a cause for hope throughout the republican period. The Ching-hsing Mining Bureau, located near Shihchiachuang in Hopeh Province, was the site of a major bituminous coal mine opened by German engineers at the turn of the century and taken over by the Chinese at the close of World War I. Under control of the provincial government, Ching-hsing operated China's largest coking facility and only coal tar extraction plant, whose principal purpose was to experiment with the manufacture of synthetic gasoline. On the whole, however, the scope of these operations was limited and the results disappointing. The Chinese paid for their failure to develop coal tar: by the mid-1930s the cost of synthetic dyes, principally aniline and indigo—the demand for which grew with the textile industry itself—exceeded $13 million per year and accounted for nearly 4 percent of China's total import bill.[49]

This failure might have been forgiven, for by the time the iron industry collapsed a new source of carbon compounds, petroleum, was taking over the field of organic chemicals. The first uniquely Western product to win an important share of the Chinese market had been a petroleum derivative, kerosene, which in the 1890s displaced native vegetable oil as the preferred fuel in lamps. Kerosene imports rose to a peak of nearly 300 million gallons in the late 1920s before declining to one third that amount in 1935. The reason for the decline was the

[48] On coal and iron, see Hou Tê-feng and Ts'ao Kuo-ch'üan, "San-shih-nien-lai Chung-kuo chih mei-k'uang shih-yeh" (China's coal mining industry during the past thirty years), in *Chung-kuo kung-ch'êng*, ed. Chou K'ai-ch'ing (cit. n. 42), Vol. II, pp. 1–25; Hu Po-yüan, "San-shih-nien-lai Chung-kuo chih kang-t'ieh shih-yeh" (China's iron and steel industry during the past thirty years), *ibid.*, pp. 1–15. On the Hanyang Iron Works, see Ch'ên T'ao-shêng, "Hu-Han k'ao-ch'a-chi" (cit. n. 7), p. 247.

[49] On Ching-hsing, see Yen Yen-tsun, "Ching-hsing lien-chiao-ch'ang fu-ch'an chih ch'i-yu" (By-product gasoline of the Ching-hsing coking plant), *Hua-hsüeh kung-yeh*, Jan. 1935, *10*(1):69–80; *China Year Book* (cit. n. 8), 1933, p. 522; 1935, p. 51; and *Data Papers on China, 1931* (Shanghai: China Institute of Pacific Relations, 1931), pp. 36–38. On coke and tar production, see Li Êrh-k'ang, "Kung-yeh kai-k'uang" (cit. n. 45), p. 339; for trade statistics, see *ibid.*, pp. 338–339; and *China Year Book*, various years.

high price of the fuel, inflated further by high tariffs, which caused many consumers to resort once again to cheaper vegetable oil and gave rise to an industry, centered in Canton, to distill kerosene from less expensive diesel fuel. In 1930, more than 160 small distilleries were set up, using a simple technology based on a locally made still. Production of kerosene by this method reached 32 million gallons in 1933, prompting foreign suppliers to raise the price of diesel fuel and lower that of kerosene. The industry survived until 1937, mainly because the provincial government paid one quarter of the costs.[50]

While the imports of kerosene decreased, those of another liquid fuel, gasoline, increased, nearly doubling from 29 million gallons in 1929 to 55 million in 1937. The reason for this rise was that China's road system expanded and the number of cars, trucks, and buses increased, while the retail price of gasoline remained steady. By the end of this period, the volume of gasoline imports was still less than half that of kerosene imports, but the strategic and economic significance of gasoline was much greater. Throughout the 1930s liquid fuels accounted for 8 to 9 percent of China's total import bill. One important goal of the Nanking government was to find a local source of petroleum or a substitute for it.[51]

The Chinese had extracted and used petroleum since traditional times. The first modern wells were sunk in 1907 by Japanese experts invited to explore fields near Yenchang, in northern Shensi Province. In 1914 the Standard Oil Company received a concession to investigate this region more fully, but the Americans found little oil and soon pulled out. Their judgment was apparently correct. Production at Yenchang peaked at around 2,000 barrels in 1916 and declined to a mere trickle in the 1930s. Refining was done in a few simple distillation pots. Yenchang, moreover, was the most productive source of petroleum in prewar China, whose peak annual output was around 2,600 barrels, less than 1 percent of total consumption. The failure of the Chinese to produce and refine petroleum, following the collapse of the iron, coke, and coal tar industries, meant that China lacked a source of raw materials for organic chemical industries of any type.[52]

CHINESE CHEMICAL INDUSTRY PRIOR TO WORLD WAR II: SUMMARY AND ANALYSIS

The cases described above suggest the extent and limits of development of the Chinese chemical industry during the Nanking Decade. Unfortunately, statistics on the economy of Republican China in general and the chemical sector in particular are not sufficient in quantity or quality to provide a reliable overview of this subject. The best data are for 1933, when D. K. Lieu (Liu Ta-chün) and the China Institute for Economic and Statistical Research conducted a survey of Chinese industry that has served as the basis for several studies. This survey can be supplemented by an even more detailed assessment of the chemical sector,

[50] On kerosene imports, see *China Year Book,* 1933, p. 168; 1936, pp. 50, 56; 1938, p. 68; on the tariff, see Frank Kai-ming Su and Alvin Barber, "China's Tariff Autonomy, Fact or Myth," *Far Eastern Survey,* June 1936, *5*(12):121; on the Canton industry, see Liu Ta-chün [D. K. Lieu], *Chung-kuo kung-yeh tiao-ch'a pao-kao* (Report on a survey of Chinese industry), 3 vols. (Shanghai: Ching-chi t'ung-chi yen-chiu-so, 1937), Vol. I, pp. 123–125.

[51] *China Year Book,* 1936, p. 56; 1938, p. 68.

[52] On petroleum in China, see *ibid.,* 1921–1922, p. 159; 1933, p. 522; 1935, pp. 49–52; Li Ch'iao-p'ing, *Chung-kuo hua-hsüeh shih* (cit. n. 28), p. 388; and Cheng Yu-kwei, *Foreign Trade* (cit. n. 1), p. 264. For petroleum import figures, see Li Êrh-k'ang, "Kung-yeh kai-k'uang" (cit. n. 45), p. 339.

carried out by the Japanese-operated South Manchurian Railway Company in 1937.

Lieu's survey covered Chinese-owned factories in seventeen provinces of China proper—excluding Manchuria, which was then under Japanese control, and the western portions of the country, which had little industry in any case. Within this area Lieu identified 2,435 factories that used power-driven machinery and employed a minimum of thirty workers. Half of these factories were in Shanghai. The average size was small, although perhaps comparable to that of factories in other countries at a similar level of development: $44,000 (167,000 yuan) in capital, 205 workers, 180 horsepower of motive power. Textiles and foodstuffs accounted for more than three fourths of total output by value. Over 95 percent of the factories were privately owned, but only one quarter were joint stock companies.[53]

Included in Lieu's survey were 148 chemical plants with a combined output of 50 million yuan; this figure represented only 4.5 percent of the total for all factories in the survey but was sufficient to place chemicals third, behind textiles and foodstuffs, on the list of Chinese manufactures. In terms of average size (178,000 yuan in capital, 186 workers) and location (57 percent in Shanghai), the chemical plants were similar to all factories, although their power consumption was low, only 61 horsepower (about one third the average). Like Chinese industry generally, the chemical sector produced mostly consumer goods: four fifths of the factories in this group made matches, soap and candles, enamelware, cosmetics, medicines, and plastics. In 1932 the ratio of profit to investment for the chemical group and the total sample was the same, 45 percent. Yet over half the chemical factories were organized as joint stock companies, which was more than twice the average and suggests a particular confidence in this sector.[54]

One reason for such confidence is indicated by another of Lieu's studies, this one limited to factories in the Shanghai area and the years 1931–1933. The Chinese economy fared poorly in the early 1930s, a period the Shanghai municipal government described as a "disastrous business depression." Yet Lieu found that during these years chemicals was one of the fastest growing sectors of the urban economy. The number of Shanghai chemical plants using power-driven machinery and employing at least thirty workers jumped from twenty-eight in 1931 to seventy-eight in 1933. Thirteen new factories were opened in five new lines: acids, calcium and magnesium carbonate, oxygen and acetylene, dyes, and plastics. During this period, the capitalization and value of output of this sector more than doubled, power consumption increased by 80 percent, and 1,700 workers were added to the work force.[55]

Lieu's study omits several of the largest and most modern chemical plants, which were established after 1933. The comprehensive survey conducted by the South Manchurian Railway Company in 1937, however, provides detailed

[53] Liu Ta-chün, *Chung-kuo kung-yeh* (cit. n. 50), Vol. I, p. 9; Vol. II, pp. 64, 160, 192, 291, 410, 422, 428. For calculation of exchange rates, see Cheng Yu-kwei, *Foreign Trade* (cit. n. 1), pp. xi, 262–263; for discussion of these issues, see Feuerwerker, *Economic Trends* (cit. n. 1), pp. 17–18, 36.

[54] Liu Ta-chün, *Chung-kuo kung-yeh* (cit. n. 50), Vol. II, pp. 48, 160, 192, 267, 401. The ratio of profit was calculated by subtracting expenses from sales and dividing the remainder by capital investment; *ibid.*, pp. 48, 64, 401, 428.

[55] On the depression, see Eastman, *Abortive Revolution* (cit. n. 26), p. 187; for the survey, see D. K. Lieu, *The Growth and Industrialization of Shanghai* (Shanghai: China Institute of Pacific Relations, 1936), pp. 77–78.

information on the two dozen leading Chinese producers of acids and sodas. These data, summarized in Table 1, include all factories already discussed except the massive Yungli ammonium sulfate plant, which did not begin operation until 1937.[56]

Incentives and Opportunities

The lure of profits earned by foreign importers initially inspired the Chinese to attempt the manufacture of chemicals—salt, soda, MSG, acids, and ammonium sulfate—themselves. Once established, chemical factories in China, as elsewhere, spawned links to other industries. The manufacture of refined salt provided the raw materials Fan Hsü-tung needed to make soda. Wu Yün-ch'u's MSG factory created a demand for hydrochloric acid; the electrolysis plant that made this acid generated a surplus of hydrogen gas, which was the chief incentive for Wu to begin producing synthetic ammonia. Seeing that the supply of this substance would exceed the demand, he opened another enterprise to convert ammonia to nitric acid. The interlocking complex of acid, soda, gunpowder, and fertilizer factories, operated by the provincial governments of Kwangtung and Kwangsi, demonstrates the habit of chemical manufacturers to "take in each other's laundry." Unfortunate, but characteristic of Republican China, was the failure to extend such links to agriculture. Attempts to manufacture chemical fertilizer came too late to bridge the widening gap between urban industry and the agricultural sector.

Capital for the chemical industry came primarily from the private sector. Both Fan Hsü-tung and Wu Yün-ch'u invested profits from their first successful enterprises to help finance later ventures. Commercial banks and individual investors bought stock in these corporations. Provincial governments operated arsenals, a few key plants in areas not served by private producers, such as the Ching-hsing coal tar facility, and one large complex in south China. The central government made subsidized loans and direct investments to establish those industries, such as alcohol and ammonium sulfate, where private enterprise had not done the job and self-sufficiency was considered a matter of national interest.

In addition to playing the role of investor of last resort, the governments of Republican China encouraged domestic chemical producers in several other ways. Beginning in 1917, salt for industrial use and, later, soda products themselves were exempted from tax. Monopolies on the manufacture of certain chemicals within designated areas protected some factories against competition from China and abroad. Tariff schedules issued after 1929, when the Nanking government revised its "unequal treaties" with the foreign powers and regained tariff autonomy, raised the rates on most chemical products manufactured in China. Rebates on railway freight charges for Chinese chemicals favored domestic products over imports, particularly in the inland cities. Comparative price data show that in the ports of entry, Tientsin and Shanghai, Yungli soda was only slightly cheaper than the Brunner-Mond brand; but further inland, in Tsinan, Taiyuan, and Hankow, it was much cheaper.[57]

[56] *Shina kōgyō* (cit. n. 6).

[57] On soda prices, see *ibid.*, pp. 114–115. On tax exemptions and monopolies, see Ou-yang I, "P'ing-tung k'ao-ch'a-chi" (cit. n. 12), pp. 97–99; Fan Jui, "Yung-li chih-chien kung-szŭ ta-shih-chi" (cit. n. 16), p. 255; and Ch'ên Chên and Yao Lo, eds., *Kung-yeh-shih tsŭ-liao* (cit. n. 11), p. 514. On

Table 1. Chinese manufacturers of sodas and acids

Name	Location	Year began operation	Capital (yuan)	Production in 1936 (metric tons) (unused capacity)
Soda Ash				
T'ung-i Soda Factory	Szechwan	1918	50,000	482
Chia-yü Soda Factory	Szechwan	1920	50,000	374
Yungli Soda Company	Tangku	1924	2,000,000	51,270
Pohai Chemical Works	Tangku	1926	600,000	4,976
Total			2,700,000	57,102
Caustic Soda				
Yungli Soda Company	Tangku	1924	2,000,000	4,976
Lao T'ien-li Factory	Tientsin	1925	15,000	603
T'ien-yüan Electrochemical Company	Shanghai	1928	600,000	1,508
Northwest Industrial Company	Taiyuan	1935	400,000	489 (1,508)
Kwangtung Provincial Electrochemical Factory	Canton	1935	1,400,000	(2,111)
Total			4,415,000	7,576 (3,619)
Sodium Sulfide				
Pohai Chemical Works	Tangku	1926	600,000	2,413
Chao-hsin Chemical Works	Shanghai	1931	200,000	1,508
Ho-chi Chemical Works	Tangku	1932	200,000	3,076
Tao-i Soda Works	Tsinan	1933	10,000	205
T'ung-shêng Chemical Works	Taiyuan	1934	23,000	362
Shen-yü Soda Works	Hangchow	1934	3,000	603
Ta-ch'ing Soda Works	Tientsin	1936	25,000	1,206
Wei-hsin Chemical Industry Society	Tsingtao	1936	500,000	2,413
Total			1,561,000	11,786
Sodium Silicate				
Lao T'ien-li Factory	Tientsin	1925	15,000	1,086
Pohai Chemical Works	Tangku	1926	600,000	4,041
Hsing Hua Soda Works	Tientsin	1929	45,000	1,267
K'ai-yüan Soda Company	Shanghai	1930	40,000	2,087
Total			700,000	8,481
Sulfuric Acid				
Liang-Kuang Provincial Sulfuric Acid Factory	Wuchow	1927	560,000	(2,606)
Tê-li Three Acid Factory	Tangshan	1931	50,000	(483)

SOURCES: For Yungli Soda: Ou-yang I, "P'ing-tung hua-hsüeh kung-yeh k'ao-ch'a-chi" (Record of an investigation of the chemical industries east of Peiping), *Hua-hsüeh kung-yeh,* Feb. 1930, *5*(1):77–110. For the Kwangtung factories: "Kuo-nei kung-yeh" (Chinese industry), *Hua-hsüeh kung-ch'êng,* March 1936, *3*(1):74. For all others: South Manchurian Railway Company, Tientsin Work Investigation Section, *Shina ni okeru san sōda oyobi chisso kōgyō* (China's acid, soda, and nitrogen industries) (Tientsin, 1937), tables on pp. 81–84, 125, 131, 137.

Table 1.—*continued*

Name	Location	Year began operation	Capital (yuan)	Production in 1936 (metric tons) (unused capacity)
Li-chung Acid Manufacturing Company	Tientsin	1933	200,000	905
K'ai-ch'êng Acid Manufacturing Company	Shanghai	1933	750,000	4,463
Kwangtung Provincial Sulfuric Acid Factory	Canton	1933	—	(4,500)
Northwest Industrial Company	Taiyuan	1934	55,000	72
Chi-ch'êng Three Acid Factory	Sian	1934	50,000	121
Total			1,665,000	5,561 (7,589)
Nitric Acid				
T'ien-li Nitrogen Gas Company	Shanghai	1936	1,000,000	1,942
Northwest Industrial Company	Taiyuan	1934	55,000	68
Chi-ch'êng Three Acid Factory	Sian	1934	50,000	36
Total			1,105,000	2,046
Hydrochloric Acid				
Pohai Chemical Works	Tangku	1926	600,000	1,206
T'ien-yüan Electrochemical Company	Shanghai	1928	600,000	1,508
Kwangtung Provincial Electrochemical Factory	Canton	1935	1,400,000	(1,810)
Total			2,600,000	2,714 (1,810)

Chinese chemical manufacturers had little difficulty obtaining the necessary equipment and skilled manpower. Generally, the Chinese were able to buy what they needed, individual machines or whole plants, from Europe and the United States. In some cases they bought used equipment at a fraction of the regular price. Foreign advisers and technicians played an important role in the construction and operation of China's arsenals, but other chemical plants, public and private, were manned almost exclusively by Chinese. The founders of several companies—Yungli, Pohai, Li-chung, T'ien-ch'u, and others—included men with training or experience in chemistry. A generation of chemical engineers was recruited by and trained in these plants. In at least one company, Yungli Soda,

shipping rebates, see ibid., p. 517. For a complaint on the low tariff on soda, which was fixed under the "unequal treaties" at 5 percent *ad valorem,* see Li Ch'iao-p'ing, "Kuan-shui yü hua-hsüeh kung-yeh" (Customs duties and the chemical industry), *Hua-hsüeh kung-yeh,* Jan. 1931, *6*(1):8–18, on p. 14. The first independent tariff schedule, fixed by the Chinese themselves under revised treaties and issued on 1 Jan. 1933, raised duties to a maximum of 50 percent on items that competed with domestic manufactures, while lowering them on other items that aided home industries; see H. D. Fong, "China's Industrialization: A Statistical Survey," in *Data Papers* (cit. n. 49), pp. 40–41. Rawski, in *China's Transition* (cit. n. 26), p. 21, reports that under this schedule, tariffs on nitric acid rose by 54 percent, on hydrochloric acid by 50 percent, and on sulfur black by 328 percent. Under pressure from Japan, a new schedule was issued in July 1934, lowering rates on textiles but raising those on chemicals and pharmaceuticals by an additional 14 to 100 percent. See also Su and Barber, "China's Tariff Autonomy" (cit. n. 50), pp. 115–122.

these men discovered the secrets of the most current techniques and built a successful enterprise despite the lack of assistance from the international cartel that controlled this industry.[58]

The raw materials used in China's chemical factories were generally available in sufficient quantity and quality and at a reasonable price. The most notable exception was coal tar, the absence of which precluded development of the organic industries. Sulfur, the key component of sulfuric acid, and nitrates, used to make nitric acid, were also a problem. Mines throughout China produced pyrites and nitrates, but the quality of the ores was often low, and the facilities for mining, refining, and transporting these minerals were inadequate to bring a steady supply of high-grade material to the factory gate. As a result, many acid factories relied on imported sulfur and saltpeter. Between the wars, Chinese production of sulfur fell to as little as 2,000 tons per year, while imports exceeded 5,000 tons. The dependence on foreign nitrates was almost as great. On the other hand, China enjoyed an abundance of inexpensive, high-quality salt, coal, limestone, and other important materials. The quality and price of their refined salt, for example, enabled the Chinese to manufacture and export soda to Japan, a country whose other industries were far in advance of those in China. On balance, the supply of raw materials constituted a plus for Chinese chemical manufacturers.[59]

Constraints

Because of all these advantages, China's chemical industry made impressive strides during the years before World War II; in spite of them, further growth was limited by the small size of the Chinese market. Comparison of production and trade figures demonstrates that in almost every case the principal constraint on this industry was insufficient demand (see Tables 2 and 3). Imports of acids and sodas increased steadily during the first part of the century to supply the growing number of factories for the bleaching, sizing, and dyeing of textiles and the manufacture of soap, paper, glass, and other products. Yungli Soda was the first to challenge foreigners for a share of the Chinese market. After 1930, when most of the factories that have been described entered production, imports in the major categories of industrial chemicals declined sharply. As these statistics show, the development of China's chemical industry followed the familiar pattern of foreign penetration to create demand for new products, followed by successful import substitution on the part of local manufacturers.[60]

By 1936, Chinese production exceeded imports in every category except caustic soda. The most striking successes occurred where they counted most, in sulfuric acid and soda ash. Yet both these products serve to illustrate the chief

[58] Ch'ên Hsin-wên, "P'ei-yang jên-ts'ai ti tso-fa" (cit. n. 17), pp. 28–34.

[59] For import figures, see Maritime Customs of China, *Returns of Trade and Trade Reports* (1906–1919); *Foreign Trade of China* (1920–1931); and *The Trade of China* (1932–1938) (Shanghai: Inspector General of Customs, indicated years). On sulfur and saltpeter, see Ting Szŭ-hsien, "Hua-hsüeh kung-yeh chih wo-chien" (cit. n. 34), pp. 76–77; Ch'ên T'ao-shêng, "Hu-Han k'ao-ch'a-chi" (cit. n. 7), p. 234; Wu Ch'êng-lo, "Hua-hsüeh kung-yeh wên-t'i" (cit. n. 9), pp. 5–8; and *China Industrial Handbooks* (cit. n. 25), pp. 658–659. On Chinese soda exports, see *Shina kōgyō* (cit. n. 6), pp. 17–18.

[60] Rawski, in *China's Transition* (cit. n. 26), p. 16, points out that between 1919 and 1936 Chinese factory cloth production increased eight times, creating a huge demand for chemicals used in dyeing and bleaching.

Table 2. Chinese imports and production of soda (metric tons)

Year	Soda ash		Caustic soda	Silicate and sulfide	All soda[a]
	Production (Yungli)	Imports			
1905–1909	—	—	—	—	13,755[b]
1910–1915	—	—	—	—	26,836[b]
1916	—	—	—	—	2,542
1917	—	—	—	—	13,030
1918	—	—	—	—	13,384
1919	—	—	—	—	53,047
1920	—	—	—	—	44,490
1921	—	—	—	—	24,650
1922	—	—	—	—	55,689
1923	—	37,290	7,372	—	53,132
1924	3,300	44,787	7,540	7,805	62,098
1925	1,800	50,161	8,687	7,821	72,563
1926	4,500	47,211	10,345	8,750	75,973
1927	14,000	52,782	9,030	10,145	79,398
1928	15,000	51,020	13,860	9,770	84,871
1929	18,000	56,368	11,503	9,758	85,914
1930	18,000	64,941	13,219	6,332	92,761
1931	23,000	46,360	12,096	6,080	72,588
1932	32,000	29,260	9,780	7,262	48,621
1933	34,000	23,767	16,560	7,137	51,759
1934	37,000	29,363	19,390	6,797	58,967
1935	45,000	27,143	19,471	4,210	54,696
1936	51,000	25,049	18,037	3,683	50,277
	Production (unused capacity)[c]				
1936	57,102		7,576 (3,619)	20,627	102,073[d] (3,619)

SOURCES: For import figures: Maritime Customs (China), *Returns of Trade and Trade Reports* (1906–1919); *Foreign Trade of China* (1920–1931); and *The Trade of China* (1932–1938) (Shanghai: Inspector General of Customs, indicated years). For Yungli soda production figures: *Shina kōgyō*, pp. 15–16.

[a] All sodas comprise, for imports: ash, bicarbonate, caustic, silicate, sulfide, and Chile saltpeter; for production: ash, caustic, silicate, sulfide, and natural soda.

[b] Annual averages.

[c] Figures from Table 1 totals.

[d] Production of natural sodas in 1936 was 16,768 tons; *Shina kōgyō*, p. 81.

limitation on this industry, the underlying weakness of the market. China's largest acid factory, K'ai-ch'êng, had a capacity of fifteen tons per day, but actual production reached only nine tons. The problem was not the quality of its product, which was good, nor the price, which declined substantially during the first years of operation. Rather, it was the inadequacy of demand: China had few or none of the industries, such as iron and steel, coal tar, chemical fertilizer, and synthetic dyes, that consume large quantities of acid; other industries used sul-

Table 3. Chinese imports and production of acids (metric tons)

Year	Sulfuric	Nitric	Hydrochloric	All acids[a]
		Imports		
1905–1915	1,420[b]	—	—	—
1924	2,859	1,456	782	5,932
1925	3,102	1,294	1,251	6,664
1926	3,811	1,723	1,692	8,260
1927	6,122	2,490	2,047	11,583
1928	5,996	2,289	2,795	12,344
1929	3,826	1,151	3,507	9,668
1930	3,083	1,263	3,473	9,109
1931	4,049	1,631	2,112	9,924
1932	3,001	1,520	1,249	7,050
1933	3,342	2,361	1,697	9,299
1934	1,317	2,962	2,040	8,762
1935	764	1,971	2,347	7,192
1936	580	342	2,440	5,890
		Production (unused capacity)[c]		
1936	5,561 (7,589)	2,046	2,714 (1,810)	10,701 (9,399)

SOURCES: For import figures: as in Table 2.
[a] All acids, besides sulfuric, nitric, and hydrochloric, for imports includes various acids for which separate figures are not available; for production, acetic acid (380 tons).
[b] Annual average.
[c] Figures from Table 1 totals.

furic acid, but in modest amounts. The same constraints held down production of soda ash. Thanks in part to concessions granted by the Chinese government, the price of Yungli soda was lower than that of the British variety in every one of the seven cities where they competed. The Chinese also exported some soda, primarily to Japan, although beyond their shores they faced international chemical combines of enormous size and sophistication that dominated most markets. At home, Yungli soda was accepted; the business was a success. Yet no one in China moved to create a second major factory for the manufacture of soda ash. The reason was lack of demand. Growth of the chemical sector depended primarily on the expansion of Chinese industry as a whole, and the horizons of both were narrow.[61]

Only in the case of caustic soda did the Chinese fail to produce more than they imported, and here, too, the fault lay partly with the local market. As indicated, many chemical industries depend upon the manufacture of various products by a single process. Quantities of these products may be adjusted to meet current demand, but each must find a market if the process is to survive. One example is the electrolysis of salt, which began as a method for producing caustic soda and

[61] On sulfuric acid, see Ting Szŭ-hsien, "Chien shê kuo-fang hua-hsüeh kung-yeh chih wo-chien" (cit. n. 34), p. 82; for soda prices, see *Shina kōgyō* (cit. n. 6), pp. 114–115. In 1933, exports of Yungli soda reached 7,000 tons, 80 percent of which went to Japan; *ibid.*, pp. 17–18.

disposed of the unwanted chlorine by converting it to bleaching powder but later flourished when demand for liquid chlorine rose; the latter replaced powder as the preferred industrial bleach, and caustic soda was relegated to the status of a by-product. The Chinese failed to recognize the importance of liquid chlorine, which was used only in a few water treatment plants, while their chlorine gas went to make bleaching powder and hydrochloric acid, the markets for which were small and shrinking. Meanwhile, foreign manufacturers diversified their operations, earned a growing share of profits from the sale of chlorine, and dropped the price of caustic soda, imports of which competed successfully against Chinese brands.[62]

Comparison with Japan and India

While the absence of similar studies for other developing countries precludes a full comparison between China and its peers, partial data on the most important industrial chemical, sulfuric acid, fill in part of this picture. Setting aside the arsenals, for which we have no precise information, Chinese production of sulfuric acid was somewhere in the range of 5,000 to 10,000 tons (66° Bé or 93.2 percent equivalent) in 1936. With the addition of the Yungli plant in 1937, the figure could have exceeded 50,000 tons annually. By contrast, Japan's output of 100 percent pure acid grew from 561,000 tons in 1926 to 1.4 million tons in 1935 and to 2.3 million tons in 1940, then declined during the war. A more meaningful comparison is with India, whose production of sulfuric acid (100 percent equivalent) rose from 22,000 tons in 1928 to 44,000 in 1941 and surpassed 100,000 tons in 1949. In sum, China's acid production was dwarfed by that of Japan but comparable to that of India until the war, which dealt a fatal blow to the Chinese and left them far behind their neighbors at the time of the Communist takeover.[63]

The opening of the Yungli ammonium sulfate plant in early 1937 marks the high point in the development of a modern chemical industry in republican China. This was the largest, most modern, and most diverse chemical facility in China proper, yet no sooner had it begun operation than the Japanese invasion halted the work of all Chinese industry. During the Nanking Decade state-of-the-art technologies, embodied in hardware manufactured abroad and introduced by foreign technicians, were brought to China to produce the basic chemicals that would promote the growth of modern, coastal industries. The Chinese mastered the methods in question and applied them with creativity and success. But this age of adoption and adaptation of proven foreign techniques stands in contrast to the years that followed, when the Chinese were obliged to build new industries with little or no outside assistance, using local resources and their own skill and imagination.

[62] Yü Jên-chün, "Tien-chieh kung-yeh" (cit. n. 28), pp. 4–9. Comparative price data show that in all categories British sodas, which accounted for 70 to 80 percent of imports, were more expensive than Chinese, but that the margin was less for caustic soda than for soda ash. See *Shina kōgyō* (cit. n. 6), pp. 90–94, 114–115.

[63] For Japanese and Indian production figures, see B. R. Mitchell, ed., *International Historical Statistics: Africa and Asia* (New York: New York Univ. Press, 1982), p. 352; on India, see R. C. Bhattacherjee, *Industrial Chemistry (Technology of Indian Chemical Industries)* (Delhi: Inter University Press, 1967), p. 13.

CHEMICAL INDUSTRY IN WARTIME CHINA, 1937–1945

The Japanese invasion brought the Nanking experiment to an end and sent the chemical industries, along with everything else in China, off in a new direction. In the space of fifteen months, from July 1937 to October 1938, the Japanese army took command of the major cities and lines of communication in north China, in the Yangtze Valley as far upstream as Hankow, and along the southern coast. Virtually the whole of "modern" China, including all the factories previously described, fell within the occupied areas. Unable to stem the enemy advance, the Nationalist Government, its army, and enterprises of all types abandoned the cities along the coast and retreated inland to Chungking, the wartime capital, and the more secure highlands of western China. The fall of Canton in 1938 closed the last sea route to the outside. Overland transport continued for a time by rail from Indochina, along the Burma Road from Rangoon, and across Sinkiang from Russia. But expansion of the war in Europe and the Pacific cut these lines or rendered them useless. From the spring of 1942 until the end of the war, sporadic flights "over the Hump" from India remained the sole link between "Free China" and the world beyond.

As a matter of survival, the Chinese built new industries deep in the hinterland with little or no help from abroad. From 1937 to 1940, 639 privately owned factories, along with more than 117,000 tons of machinery and equipment, were hauled from their original sites, most on the lower Yangtze, to the rear areas. The government also built or helped to finance enterprises of all types, particularly the chemical industry. In the public sector, the National Resources Commission (NRC) operated more than one hundred major enterprises, most of which were for electric power and chemical production, including eight alcohol, two synthetic oil, and five acid and soda factories. In the private sector, the largest recipient of government aid was the chemical industry, which, with more than $17 million in loans and $19 million in investments, received a third of the total outlay. By 1944 the Ministry of Economic Affairs (MEA) had registered nearly 5,000 factories, of which the largest portion, over one quarter, was devoted to chemicals. Starting from the base year 1938 (100), the MEA index of industrial production for 1944 stood at 352, a figure exceeded by that for every chemical product: soda ash, 394; caustic soda, 671; bleaching powder, 550; sulfuric acid, 457; hydrochloric acid, 433; alcohol, 2,464; and gasoline (including synthetic gasoline), 83,154.[64]

Chemicals

The leader of the acid industry was the NRC's Kiangsi Acid Manufacturing Plant, which made 4 tons of different types of acid per day. By the end of 1941 there were thirteen other factories in the rear areas, claiming a combined

[64] On factories moved to Szechwan, see Cheng Yu-kwei, *Foreign Trade* (cit. n. 1), p. 108. On the public sector, see *The China Handbook* (Chungking: Chinese Ministry of Information; New York: Macmillan), for the following years: *1937/43*, pp. 433–436; *1937/44*, pp. 277–278; *1937/45*, pp. 364–366; on the private sector, see *ibid.*, *1937/43*, pp. 436–440; *1937/44*, p. 289; for MEA-registered factories, see *ibid.*, *1937/45*, pp. 363–364; for the MEA index, see *ibid.*, *1937/44*, p. 278; 1937/45, p. 369. This source succeeded *China Year Book* (cit. n. 8).

monthly output of 181 tons of sulfuric, 4 tons of nitric, and 45 tons of hydrochloric acid. Two of these were provincial plants, representing Kiangsi and Chekiang. The largest private factories, all in Szechwan, boasted capacities of 30 to 50 tons per month.[65]

Western Szechwan, whose brine wells had supplied salt to inland China for centuries, emerged as the center of the soda industry. By the late nineteenth century, thousands of wells drew a rich salt broth from the mountains west of Chungking. Sharp metal bits, raised by human and animal labor, hammered through rock and soil for five to ten years, often to a depth of 3,000 feet, before striking "success." The brine was drawn up in bamboo pipes, which were allowed to fill with liquid, sealed by a valve, and raised by ropes. Natural gas, tapped at the deepest levels, reached the surface under its own pressure and was burned to evaporate the brine, yielding pure white crystals of salt.[66]

Traditionally this salt was sold as a flavoring and preservative, but the growth of the Szechwan paper industry in the early twentieth century created a demand for soda and an additional market for minerals extracted from the brine. The needs of eastern Szechwan, about 4,500 tons per year, were filled by imports of high-grade soda, one third of which came from Yungli, two thirds from Brunner-Mond. Western Szechwan was beyond the reach of supplies from the coast, but wells of the Pengshan region yielded sodium sulfate, which was used to make soda by the Leblanc method, once the premier process in the chemical industry but by this date no longer practiced in most parts of the world. Factories using modern techniques, the first of which was set up in 1912, manufactured a product containing 50 percent sodium carbonate, making this region self-sufficient in soda ash.[67]

Following the Japanese invasion, Fan Hsü-tung, Hou Tê-pang, and engineers from the Yungli plant withdrew to Szechwan, where they established a salt refinery at Tzuliuching and a soda factory at Wutungchiao. Their initial intent was to recreate the Solvay system that had worked so well in Tangku. However, this process converts a relatively low percentage (70 percent) of salt to soda and requires very pure sodium chloride, which could be extracted from well brine only at enormous cost. In 1938 Fan and Hou traveled to Germany in search of a new technology to overcome these problems. Because of their commitment to Japan, however, the Germans refused to transfer patents to China. Undaunted, Hou proceeded to New York, where he directed research, on-site and by long-distance, in Hong Kong, Shanghai, and Szechwan. Finally, in 1943, successful trials were completed using the "Hou united soda method," which combined the Solvay and synthetic ammonia (Haber) processes in continuous operation to make pure soda from carbon dioxide, ammonia, and salt. The virtue of this process was that it converted all of the salt to useful products—sodium carbonate (soda) and ammonium chloride (fertilizer). By this date, however, the blockade of Free China prevented delivery of the required machinery. Yungli and other factories fell back on the more primitive, but reliable, Leblanc method, using equipment built on the spot. The Wutungchiao plant reached a monthly output of

[65] *China Handbook, 1937/43,* pp. 436, 445.
[66] Li Jung, "An Account of the Salt Industry at Tzu-liu-ching," *Isis,* Nov. 1948, *39*(118):228–234; and Li Ch'iao-p'ing, *Chemical Arts* (cit. n. 12), pp. 61–65.
[67] *Shina kōgyō* (cit. n. 6), pp. 70–78.

180 tons; many smaller factories produced 30 to 50 tons per month. By 1944 annual production of soda ash in the rear areas exceeded 5,600 tons.[68]

The NRC's Chemical Supplies Plant in Kunming was a leading producer of both soda ash and caustic soda, the latter made by the lime or chemical method. The only electrolysis plant in wartime China was the T'ien-yüan Electrochemical Company, which moved from Shanghai to Hong Kong and, finally, to Chungking. In 1942 T'ien-yüan had 100 electrolytic cells in operation and produced 150 tons of caustic soda, 165 tons of bleaching powder, and 30 tons of hydrochloric acid per month. By the end of the war, annual production of caustic soda for the entire region exceeded 2,700 tons. Owing to the scarcity of this product, distribution was regulated, with highest priority assigned to factories making soap, candles, paper, oil, and dyes.[69]

Despite these efforts, the industrial production of Free China was in fact quite limited, reaching a peak, in 1943, of less than one eighth the total output achieved before the war in all of China proper, excluding Manchuria and Taiwan. While estimates vary, production of acids and sodas probably reached 7,000 to 9,000 tons, compared with the prewar peak of around 60,000 tons; this production was on a par with the performance of wartime industry as a whole (see Table 4).[70]

Fuels

In contrast to the mediocre record of industrial chemical manufacture, one of the great achievements of wartime China lay in the production of liquid fuels, both from crude petroleum and by synthetic processes. As the war neared, the Chinese government had grown increasingly concerned about its dependence on foreign oil and stepped up exploration for new sources. Investigation of the Shensi fields produced no new results, but in 1935 news surfaced of oil in Yumen County, Kansu Province, deep in the interior and far from the centers of Chinese industry and commerce. An American geologist hired to study the site issued a pessimistic report, and interest in Kansu waned. With the outbreak of war and the retreat inland, however, a Chinese team was sent to investigate the region. Based on this team's more optimistic findings, technical personnel were shifted

[68] Inapplicable at the time of its invention and resisted for years thereafter, the Hou soda method eventually gained acceptance and stands as a signal contribution of the chemical industry of wartime China. Having chosen to remain in China after the revolution, Hou was sent by the government in November 1949 to inspect chemical factories at Dairen, in southern Manchuria. Noting the proximity of Solvay and ammonia plants, he proposed to combine them, using the method that bears his name. Peking approved the plan and work began, but it was interrupted in the mid 1950s by Soviet advisers who opposed the use of ammonium chloride as a fertilizer, thus dismissing a major justification for using this technique. During the Great Leap Forward, which was in part a rebellion against Soviet tutelage, Hou was appointed vice minister of chemical industry, after which development of the combined soda method resumed. In 1964 a national scientific inspection committee proclaimed the project a success, and it became a model for the manufacture of soda throughout China. See Sung Tzu-ch'êng, "Hou Tê-pang" (cit. n. 18), pp. 34–37; Li Chih-ch'uan and Ch'ên Hsin-wên, " 'Hou-shih chien-fa' ti tan-shêng ho fa-chan" (Birth and development of the "Hou Soda Method"), *Hua-hsüeh t'ung-pao* (Chemistry), 1982, *8*:475–479, on pp. 475–478. On the Leblanc method in China, see Wu Ch'êng-lo, "Suan-chien hua-hsüeh kung-ch'êng" (cit. n. 42), p. 1; and Li Ch'iao-p'ing, *Chung-kuo hua-hsüeh shih* (cit. n. 28), p. 373; on soda ash production, see *China Handbook* (cit. n. 64), *1937/43*, p. 445; *1937/45*, p. 372.

[69] On the Chemical Supplies Plant, see *China Handbook, 1937/43*, p. 436; on T'ien-yüan, see *ibid.*, pp. 445, 449; and Ch'ên Chên and Yao Lo, eds., *Kung-yeh-shih tsŭ-liao* (cit. n. 11), p. 523; on annual production, see *China Handbook, 1937/45*, p. 372; and on priorities, see *ibid., 1937/43*, p. 463.

[70] Cheng Yu-kwei, *Foreign Trade* (cit. n. 1), pp. 264–265.

Table 4. Production of chemicals in wartime China (metric tons)

Product	Year				
	1940	1941	1942	1943	1944
Sulfuric acid	561	411	598	596	712
Nitric acid	10	12	19	28	24
Hydrochloric acid	317	197	279	226	549
Soda ash	1,290	1,598	2,209	4,232	5,676
Caustic soda	397	607	741	2,282	2,768
Sodium sulfide	21	60	45	68	77
Bleaching powder	103	468	696	646	963

SOURCE: Ministry of Economic Affairs, cited in Chinese Ministry of Information, *The China Handbook, 1937/45* (New York: Macmillan, 1950), pp. 371–372.

from Shensi to Yumen, and drilling began in 1939. Within a year they had struck oil.[71]

Owing to the difficulty of wartime transportation, the Kansu Petroleum Bureau, set up to manage drilling and refining, could not obtain high-quality foreign equipment. All facilities connected to the Kansu enterprise were built and operated by Chinese using local resources. One refinery located in the Yumen fields first used shell stills, relatively primitive devices later replaced by more modern pipe stills, to produce straight distillates. A second refinery, located at an unnamed site east of the fields, included a semi-cracking unit. By 1944 the output of these refineries reached 6.4 million gallons of petroleum products, mostly gasoline, along with some kerosene and diesel. Further exploration by the National Resources Commission in Szechwan and other provinces under Nationalist control revealed some natural gas but no petroleum.[72]

The shortage of petroleum spurred the Chinese to seek other sources of liquid fuels. One possibility was coal or shale, which had been studied without notable success before the war. After 1937 several coking facilities were set up in the rear areas, and researchers at the West China Academy of Sciences, near Chungking, tested samples of Szechwan coal to determine potential yields. The NRC operated a coal distillation plant at Kienwei, in western Szechwan, to make synthetic gasoline and other products from the rich deposits of bituminous coal found in that region. Kienwei gasoline, which was high in octane, was used for aviation fuel but was never produced in large volume.[73]

While attempts to make liquid fuel from coal yielded meager results, the Chinese found a more pliable source of hydrocarbons in living plants. The extraction

[71] See Li Ch'iao-p'ing, *Chung-kuo hua-hsüeh shih* (cit. n. 28), pp. 381, 390; *China Handbook, 1937/43*, pp. 483–484; Shên Chin-t'ai, "Hua-hsüeh kung-ch'êng-hsüeh" (Chemical engineering), in *Chung-hua min-kuo k'o-hsüeh chih*, ed. Li Hsi-mou (cit. n. 44), p. 6; Shên Chin-t'ai, "Chung-kuo hua-hsüeh-shih kai-shu" (Summary of the history of chemistry in China), in *Chung-kuo k'o-hsüeh-shih lun-chi* (Collected essays on the history of science in China), ed. Lin Chih-p'ing [Ling Chih-Bing] (Taipei: Chung-hua wên-hua ch'u-pan shih-yeh wei-yüan-hui, 1958), pp. 40–42.

[72] See Cheng Yu-kwei, *Foreign Trade* (cit. n. 1), p. 264.

[73] On the West China Academy of Sciences, see Tsêng Chao-lün, "Chung-kuo hua-hsüeh chih chin-chan" (cit. n. 21), p. 1523; and Li Lo-yüan, "Low Temperature Carbonization of Szechwan Coal" (in English), *Hua-hsüeh kung-ch'êng*, Dec. 1939, *6*(3–4):33–37; on Kienwei, see *China Handbook, 1937/44*, p. 278.

of oil from soybeans and other oil-bearing seeds, for both food and fuel, was a major industry in traditional China. In the early twentieth century foreign investors introduced power-driven presses, and a modern industry developed, centered in southern Manchuria and largely under Japanese control. Chinese in Shanghai, Canton, and other cities adopted these methods; by 1931 there were more than one hundred modern oil-pressing factories in China proper. Meanwhile, substandard oils produced in the hinterland were refined, using lime or caustic soda to precipitate the impurities, in factories in and around Hankow. Again, the new method was pioneered by foreigners; the Chinese followed their lead. By the early 1930s modern plants to press vegetable oils and purify them by chemical techniques were an established part of Chinese industry.[74]

Research into the extraction of gasoline and other fuels from vegetable oil began in the early 1930s at the National Bureau of Industrial Research and the Sinyuan Fuels Laboratory in Nanking. In 1937 Sinyuan set up an experimental plant to produce gasoline and kerosene by heating vegetable oil in the presence of an aluminum chloride catalyst. Based on the success of these experiments, the NRC sent a team of scientists from this lab to establish a factory in Chungking. Production at this plant, the Tung-li Oil Works, began in the spring of 1940, using tung oil extracted from the seeds of the tung tree native to western China.[75]

Initially the Tung-li factory attempted thermal cracking of oil in locally made pipe stills. By the spring of 1940 production had reached 500 gallons of gasoline per day, but the operation could not be judged a success. Thermal cracking requires sophisticated equipment, made of special alloys capable of withstanding high temperatures and pressures, that was not available in wartime China. Work at the Tung-li plant was repeatedly interrupted by machine corrosion, damage, and breakdowns. The gasoline produced was of poor quality, containing excessive amounts of fatty acids and having a low octane rating. As a result of these problems, Tung-li and other factories in the rear areas shifted to a chemical process, saponification, in which the tung oil was mixed with lime to form a calcium soap that could be distilled to produce a crude petroleum substitute. This technique yielded high-grade gasoline equal in volume to 20 percent of the raw tung oil.[76]

By 1942 the Tung-li works turned out 4,000 gallons of gasoline per month; its performance attracted others into this field. Chungking alone had thirteen vegetable oil refineries, both government and private, that produced liquid fuels with locally manufactured equipment and had a combined monthly output of more than 18,000 gallons of gasoline, 13,000 gallons of kerosene, and 80,000 gallons of diesel. This industry spread to other parts of Szechwan, and production expanded rapidly[77] (see Table 5.)

More successful than the attempt to manufacture synthetic fuels was that to

[74] Li Ch'iao-p'ing, *Chung-kuo hua-hsüeh shih* (cit. n. 28), pp. 413–415.

[75] For a sample of research on the synthesis of gasoline from vegetable oil, see articles in *Kung-yeh chung-hsin,* Jan. 1935, *4*(1):64–69; Aug. 1935, *4*(8):412–415; Dec. 1935, *4*(12):466–479; Feb. 1936, *5*(2):66–70. On the Tung-li Oil Works, see Shên Chin-t'ai, "Hua-hsüeh kung-ch'êng-hsüeh," p. 5; and Shên, "Hua-hsüeh-shih kai-shu," p. 39 (both cit. n. 71).

[76] Shên Chin-t'ai, "Hua-hsüeh-shih kai-shu" (cit. n. 71), p. 39; Ch'ên T'i-jung, "San-shih-nien-lai Chung-kuo chih lien-yu kung-yeh" (China's oil refining industry during the past thirty years), in *Chung-kuo kung-ch'êng,* ed. Chou K'ai-ch'ing (cit. n. 42), Vol. II, pp. 1–4.

[77] Ch'ên T'i-jung, "Lien-yu kung-yeh" (cit. n. 76), p. 4.

Table 5. Production of synthetic gasoline from vegetable oil (1,000 gallons)

	Year				
	1940	1941	1942	1943	1944
Government	14 (1)	38 (3)	204 (12)	441 (16)	408 (13)
Private	8 (3)	72 (12)	74 (17)	201 (9)	157 (13)
Total	22 (4)	110 (15)	278 (29)	642 (25)	565 (26)

NOTE: Number in parentheses is the number of factories.
SOURCE: Ministry of Economic Affairs, cited in the *The China Handbook, 1937/45*, p. 370.

Table 6. Production of ethanol (1,000 gallons)

	Year				
	1940	1941	1942	1943	1944
Government	1,144 (6)	1,653 (22)	3,517 (31)	4,551 (44)	4,470 (43)
Private	2,715 (37)	4,504 (159)	5,835 (118)	6,164 (131)	6,624 (127)
Total	3,859 (43)	6,157 (181)	9,352 (149)	10,715 (175)	11,094 (170)

NOTE: Number in parentheses is the number of factories.
SOURCE: Ministry of Economic Affairs, cited in *The China Handbook, 1937/45*, p. 370.

produce a gasoline substitute, alcohol. Ethyl alcohol in its anhydrous (water-free or pure) state may be mixed with gasoline in the ratio of one to four and burned in a normal internal combustion engine. During the 1930s, the Nationalists produced enough ethanol to meet local demand and experimented with its use as a gasoline substitute. After 1937 the government invested heavily in alcohol plants as a means of stretching the limited fuel supply. The first distillation towers built entirely by Chinese were erected in Szechwan in August 1938 by technicians from the China Alcohol Factory. By 1944 there were 51 alcohol factories (12 run by the government, 39 operated privately) in Szechwan, most with an annual output of 250,000 gallons and a few three times this large (see Table 6). Over one hundred factories of various sizes were scattered throughout the other provinces under Nationalist control. The principal raw material used in these factories was molasses or a strong spirit ("shao-chiu" or "kan-chiu") made from it. By the end of the war, total production neared one million gallons per month.[78]

The effects of World War II on the Chinese chemical industry were mixed. While the war dealt a severe blow to those industries in which the most progress had been made and the prospects for future growth were brightest—acids, sodas, and fertilizers—it also provided an impetus to the production of organic chemicals, which had been lacking in prewar China. War separated the Chinese from the materials, machines, blueprints, and advice that had stimulated technical change and economic growth. Yet the isolation from foreign contact and supply prompted innovation in the design, construction, and engineering of factories of all types. In this process, as one observer, Chou Fa-ch'i, noted, the various

[78] Lu Pao-yü, "Chiu-ching kung-yeh" (cit. n. 45), pp. 2–3.

segments of the Chinese chemical enterprise were brought more closely together. Denied the special equipment and materials previously imported from abroad, industrialists in China's hinterland had to make the most of local resources and methods. Denied the physical and psychological security of their prewar professions, scholars in wartime China had to relate their personal welfare to the survival of the state. Universities and research institutes turned to the problems of production, scientists entered the factories, and industrial managers looked to the scholarly community for help. When the Nationalists returned to the coastal cities the factories of Free China were left behind, but those who built the industries of the hinterland brought the experience back with them.[79]

FOREIGN-OWNED CHEMICAL FACTORIES IN CHINA: MANCHURIA

Thus far we have mentioned the role of foreign trade but have said nothing about the manufacture of chemicals by foreigners on Chinese soil. Measured in terms of capital investment, the foreign presence seems overwhelming. In 1936 foreign investment in manufacturing in China, excluding Manchuria but including Hong Kong, was $332 million. More than half this amount was invested in textiles, while the second largest category, chemicals, accounted for $75 million, or 22 percent of the total. (Of this amount, $63 million was British.) In contrast, the total capitalization of the factories included in Lieu's survey was only $107 million (Ch$407 million), of which the chemical group accounted for less than $7 million (Ch$26 million). In sum, foreigners invested more than ten times as much in chemical production in China as the Chinese themselves.[80]

Production figures tell a different story. Liu Ta-chung and Yeh Kung-chia have shown that in 1933 Chinese firms accounted for two thirds of the gross value of factory output in all of China and for 78 percent of the output in China proper (excluding Manchuria). Figures for the chemical sector show even greater dominance by the Chinese: 71 percent in all of China, 82 percent in China proper. In both cases, the foreigners invested more capital, but the Chinese produced more goods. Albert Feuerwerker has argued that output is a more accurate measurement of the Chinese-foreign balance because most Chinese factories were engaged in light manufacturing, where labor could be substituted for capital. While this may be true, it is interesting that Chinese chemical factories accounted for a greater share of production in their sector than did Chinese manufacturers as a whole, even though the chemical producers had a higher ratio of capital to labor than that for all Chinese factories. In short, China's chemical sector competed more effectively against foreign producers within China than Chinese industry generally and did so with less capacity for labor substitution.[81]

Foreign manufacturers, like the Chinese themselves, mostly made consumer

[79] Chou Fa-ch'i, "Hua-hsüeh yen-chiu yü hua-hsüeh kung-yeh" (Chemical research and chemical industry), *Hua-hsüeh kung-ch'êng*, Dec. 1939, 6(3–4):66–67.

[80] See Hou Chi-ming, *Foreign Investment and Economic Development in China, 1840–1937* (Cambridge, Mass.: Harvard Univ. Press, 1965), pp. 13, 16, 81; C. F. Remer, *Foreign Investments in China* (New York: Macmillan, 1933); and Liu Ta-chün, *Chung-kuo kung-yeh* (cit. n. 50), Vol. II, pp. 48, 64.

[81] Liu Ta-chung and Yeh Kung-chia, *Economy of Chinese Mainland* (cit. n. 1), pp. 142–143, 426–428; and Feuerwerker, *Economic Trends* (cit. n. 1), pp. 35–36. For a comparison of chemical and all factories, see Liu Ta-chün, *Chung-kuo kung-yeh* (cit. n. 50), Vol. II, pp. 48, 64, 267, 291.

goods. The first foreign firm to manufacture a chemical product in China, J. Llewellyn and Company, established in Shanghai in 1853, made drugs and cosmetics. During the 1880s foreigners set up factories to produce matches, glass, paper, and soap. Major Brothers, founded in 1901, manufactured acids with limited success, but this was the only foreign-owned producer of basic chemicals in China proper. As Robert Dernberger has pointed out, given the limited development of the Chinese economy there was little market for producer goods in the chemical or any other sector. The single notable exception was Manchuria, where the Japanese carried out a massive program of industrialization.[82]

Industrial development came late to Manchuria, in China's extreme northeast, a region rich in natural resources but lacking political unity and leadership. During the first third of the present century, the economy of Manchuria was dominated by agriculture and handicrafts, and even after the creation of the Japanese puppet state of Manchukuo in 1932, Tokyo sought to make this region, like other tributaries of its empire, a supplier of raw materials and a consumer of manufactured goods. That strategy changed in the mid-1930s, when the approach of war and recognition of Manchuria's vast potential persuaded Japan's rulers to transform the region into an integrated, self-sustaining industrial machine.

The industrialization of Manchuria took place under official guidance and at official expense. The Manchukuo government ran several enterprises directly, but its most important instruments were two enormous joint stock companies (50 percent public, 50 percent private): the South Manchurian Railway and the Manchurian Industrial Development Corporation. Through these channels over $2 billion flowed into the region, most of it in the form of machinery and other producer goods. The rate of gross investment in fixed capital grew from 9 percent in 1924 to 23 percent in 1939—compared with a ceiling of 5 percent for China proper. During the period of 1932–1945, the output of Manchurian factories and mines grew at a yearly rate of 14 percent. This expansion leveled off after 1941, as Japanese resources were drained by the war in the Pacific. Still, with less than 10 percent of China's population, Manchuria accounted for almost one third of the country's peak factory production before 1949. Given Tokyo's mission, it mattered little that agriculture and light industry lagged or that many enterprises were run at a loss. This was a program of force-fed industrialization, and it worked.[83]

There was no large-scale manufacture of chemicals in Manchuria before 1932. Total investment in this sector, other than for the extraction of bean oil, was only $7.5 million. During the next thirteen years, however, the Japanese poured $136 million into the production of chemicals and a somewhat smaller amount into the manufacture of liquid fuels. Between 1937 and 1940 the chemical sector received more than 10 percent of all new investments, placing it third, behind mining (55 percent) and metals (25 percent), in this category. The major chemical manufacturers were in Mukden and Dairen, with coke by-product plants at Anshan,

[82] See Hou Chi-ming, *Foreign Investment* (cit. n. 80), pp. 85–88; and Robert Dernberger, "The Role of the Foreigner in China's Economic Devlopment, 1840–1949," in *China's Modern Economy in Historical Perspective*, ed. Dwight H. Perkins (Stanford: Stanford Univ. Press, 1975), pp. 37–39.

[83] See Feuerwerker, *Economic Trends* (cit. n. 1), pp. 23–24; Cheng Yu-kwei, *Foreign Trade* (cit. n. 1), pp. 189–194; F. C. Jones, *Manchuria Since 1931* (Toronto: Oxford Univ. Press, 1949), pp. 140–162; and Edwin W. Pauley, *Report on Japanese Assets in Manchuria to the President of the United States, July 1946* (Washington, D.C.: GPO, 1946), pp. 16ff, 74.

Penhsihu, and Fushun and other factories scattered along the railway from Kirin and Changchun in the north to Chinchow and Dairen in the south. With the exception of pyrites, which were imported from Japan and China, all raw materials were obtained and most products consumed in Manchuria. By the end of the war, total plant capacity for major industrial chemicals neared 900,000 tons (see Table 7).[84]

Among the region's largest chemical producers were the iron and steel works at Anshan and Penhsihu, which fostered a coal tar industry of the type lacking in China proper. Anshan, the site of Manchuria's richest iron mine, lacked coal, which had to be imported from neighboring mines; but from the opening of the first blast furnace in 1919 this plant produced its own coke and coke by-products, including ammonia, which was combined with sulfuric acid also manufactured at the site to make ammonium sulfate at a peak rate of 24,000 tons per year. Daily capacity of the by-product plant was 120 tons of benzol, refined to make solvents, fuels, explosives, and dyes, and over 400 tons of coal tar, distilled to anthracene, naphthalene, creosote, and pitch. Capacity for synthetic gasoline production exceeded 40,000 barrels per year. The Penhsihu iron works, similar to but smaller than the Anshan complex, sat atop a rich bituminous coalfield and produced coal, coke, and coke by-products. In the early 1930s extraction of oil reached 3,000 barrels annually. By 1944 expansion of the works (a sister plant was opened across the river at Kungyuan in 1938) raised annual output to 20,000 tons of crude tar, 7,000 tons of sulfuric acid, and 4,700 tons of ammonium sulfate.[85]

The largest factory devoted exclusively to chemicals was the Manchuria Chemical Industry Company, established in Dairen in 1935. This was an integrated facility similar to the Yungli complex at Hsiehchiatien. The Dairen plant employed the Wade nitrogen fixation process developed in Germany and reached a peak output of 229,000 tons of ammonium sulfate in 1938, by far the largest volume of chemical fertilizer produced by any single plant in China. This factory also made sulfuric acid, first in lead chambers and later by the contact method, and nitric acid, presumably by the oxidation of ammonia (Ostwald process).[86]

Also located in Dairen was the Manchuria Soda Company, established in 1936 to manufacture soda ash from sea brine by the Solvay method. By the end of the war, the capacity of the Dairen factory reached 60,000 tons. In 1939 this company opened three more plants to make caustic soda by the electrolysis of sea salt: at Dairen (3,000 tons per year), Mukden (2,000 tons), and Kaiyuan (4,500 tons). Two other factories in Mukden produced caustic soda by the same method. By 1941 Manchuria was self-sufficient in this key industrial chemical. The chlorine gas generated by electrolysis was used to make bleaching powder and hydrochloric acid.[87]

[84] See Cheng Yu-kwei, *Foreign Trade* (cit. n. 1), p. 191; *The Manchukuo Year Book, 1942* (Tokyo), pp. 515–517.

[85] For Anshan production figures, see Hu Po-yüan, "Kang-t'ieh shih-yeh" (cit. n. 48), p. 3; for other details on Anshan, see Pauley, *Japanese Assets* (cit. n. 83), pp. 104, 109, 201, Appendix 5, 2-A-1. On Penhsihu in the 1930s, see *China Year Book* (cit. n. 8), 1935, pp. 51–53; on Penhsihu in 1944, see Pauley, *Japanese Assets,* pp. 101–105, App. 5, 2-A-12.

[86] See Li Ch'iao-p'ing, *Chung-kuo hua-hsüeh shih* (cit. n. 28), p. 372; Jung-chao Liu, *China's Fertilizer Economy* (cit. n. 42), pp. 7–9, 128; Pauley, *Japanese Assets,* p. 201.

[87] Yü Jen-chün, "Tien-chieh kung-yeh" (cit. n. 28), p. 4; *Manchukuo Year Book, 1942* (cit. n. 84),

Table 7. Industrial capacity, Manchuria, 1945 (metric tons)

Sulfuric acid	351,000	Bleaching powder	3,500
Nitric acid	37,500	Ammonia	68,600
Hydrochloric acid	5,750	Ammonium sulfate	319,000
Soda ash	60,000	Ammonium nitrate	15,500
Caustic soda	16,500	Total	877,350

SOURCE: Edwin W. Pauley, *Report on Japanese Assets in Manchuria to the President of the United States, July 1946* (Washington, D.C.: GPO, 1946), pp. 185; 201, Table C-2.

The large and diverse chemical industry of Manchuria included several other important products. By the end of the war there were eight major ethanol plants in the region, with a peak production of at least 5.6 million gallons. The Manchuria Gas Company, established in Changchun in 1925, produced more than one-half billion cubic feet of coal gas per year and spun off coal tar by-products, which were sold to other chemical factories. The Manchuria Electrochemical Industry Company of Kirin produced 15,000 tons of calcium carbide annually for use in the manufacture of synthetic rubber. Arsenals at Mukden and other sites made sulfuric and nitric acids, although few details exist on these operations.[88]

The most pressing need in Manchuria, as in China proper, was for gasoline and other petroleum products. Despite extensive exploration, no natural petroleum was found. There were three petroleum refineries in the region, one built by the Manchukuo government and private interests and two by the Japanese army, with a combined capacity of 2.7 million barrels per year. Owing to the shortage of crude oil, however, these refineries accounted for only 10 percent of Manchuria's total liquid fuel production.[89]

To make up for the lack of petroleum, the Manchukuo government invested in coal liquefaction, which received more than 20 percent of all funds in the first Five-Year Plan (1936–1941). Seven plants were built, two in the central Manchurian cities of Harbin and Kirin, the others nearer the main coalfields of the southeast, in Mukden, Fushun, Chinhsi, Chinchow, and Tashihchiao. One of these used Fischer-Tropsch equipment from Germany, which extracts carbon monoxide and hydrogen from coal and combines them under proper temperature and pressure in the presence of a catalyst. Two were low-temperature carbonization plants. The rest were for the hydrogenation of tar produced on-site or obtained from carbonization plants in other parts of Manchuria. At least two of this last group also used German equipment. Together, the seven plants had a planned capacity of more than 1.5 million barrels of liquid fuels per year, but the first of them did not open until 1943, and only four were in operation by the end of the war. Production peaked in 1944 at less than 60,000 barrels, about 6 percent of Manchuria's total liquid fuel output.[90]

pp. 543–544; Li Ch'iao-p'ing, *Chung-kuo hua-hsüeh shih* (cit. n. 28), p. 376; and Pauley, *Japanese Assets* (cit. n. 83), pp. 201, App. 10, 1-C-1, 20-C-1.

[88] On Manchurian chemical producers, see Pauley, *Japanese Assets*, pp. 187, 195; on the arsenals, see *China Year Book* (cit. n. 8), 1933, pp. 544–545.

[89] See Pauley, *Japanese Assets*, pp. 162–170, App. 9, 6-I-1, 19-E-1; capacity and production figures on p. 183.

[90] On the first Five-Year Plan, see Jones, *Manchuria Since 1931* (cit. n. 83), pp. 152–154; on coal liquefaction plants, see Pauley, *Japanese Assets*, pp. 170–183.

By far the largest producers of oil in Manchuria were the shale plants at Fushun. By the 1930s Fushun, a coal mining center for 800 years, boasted the largest open-pit mine in the world. Oil-shale deposits that overlay the rich bituminous coal beds had to be removed as the first step in open-pit mining; with a generous supply of this raw material, the first extraction plant began operation in 1929. The process used in this plant was similar to that of a gas producer for the recovery of tar: crushed and screened shale was fed into the top of a retort and heated, then the gases were drawn off to a condenser. The resulting crude oil was cracked in a separate unit. Sulfuric acid, made in the same plant by the contact method, was introduced into the gas washer to form ammonium sulfate at a rate of over 20,000 tons per year. The success of the first plant led to construction of two more in 1938 and 1944. Production peaked in 1943 at more than 1.3 million barrels, before tapering off at the end of the war. During the period 1937–1945, oil-shale extraction accounted for 85 percent of all Manchurian oil products.[91]

THE POSTWAR PERIOD, 1945–1949

The postwar recovery of Chinese industry was slow and difficult. Before the victors arrived on the scene, most Japanese enterprises in Manchuria had been stripped or destroyed, many factories in Taiwan damaged by Allied bombing, and industrial plants throughout China worn thin by misuse and neglect. Reconstruction in Manchuria and north China was obstructed by civil war, while high inflation made a shambles of the economy in areas under Nationalist control. Overwhelmed by these larger forces, the chemical industry made a slow recovery.[92]

Following V–J Day, Chinese owners gradually retook control of factories temporarily occupied by the invaders, while the National Resources Commission was charged with taking over Japanese- and puppet-owned enterprises. This process began in China proper in September 1945, in Taiwan in November 1945, and in Manchuria, following the Soviet departure, in May 1946. Altogether, the NRC seized more than 2,000 units worth an estimated $1.8 billion: $1.2 billion in Manchuria, including $96 million in chemical plants and $81 million in liquid fuels; $212 million in Taiwan, with $19 million in chemicals and $7 million in liquid fuels; and the rest in China proper, for which we have no breakdown by sector.[93]

The Chinese derived limited benefit from the reoccupation of Manchuria. The substantial industries of this region had been built with Japanese capital, engineered by Japanese technicians, and run by Japanese managers. Chinese had participated only as low-level laborers and consumers of the simplest end-products. Much of the best hardware was removed by the Red Army. Edwin Pauley, who headed an American inspection team that toured this region in the summer of 1946, estimated losses caused by the Soviet occupation at $2 billion

[91] On the Fushun plant, see Pauley, *Japanese Assets,* pp. 77–78, 162–166, 183, 201, App. 4, I-B-4, App. 9, 1-I-1; see also Li Ch'iao-p'ing, *Chung-kuo hua-hsüeh shih* (cit. n. 28), p. 372; and Jones, *Manchuria Since 1931,* p. 158.

[92] Cheng Yu-kwei, *Foreign Trade* (cit. n. 1), p. 156 notes that from Dec. 1945 to Aug. 1948 commodity prices in Shanghai increased by more than 5,000 times and foreign exchange by more than 7,000 times.

[93] *Ibid.,* pp. 163, 266.

and reduction in productive capacity for most basic industries at 50 to 75 percent. Even if the Chinese could restore and learn to run these factories, moreover, the results were hard to foresee, for the industries had been force-fed with external capital and operated on a "nonprofit" basis. Many enterprises seemed unlikely to stand the test of the marketplace.[94]

Reports on the Manchurian chemical industry following the Russian withdrawal present a mixed, but overall bleak, picture. Two of the most important plants, the Manchu Chemical Industry Company and the Manchu Soda Company, were in Dairen, which remained under Russian control and off-limits to the Americans. One other, the Fushun East Oil-Shale Plant, was controlled by the Chinese Communists and similarly inaccessible. Two factories, the Manchu Soda Company at Kaiyuan and the coke by-product plant at Penhsihu, had been completely dismantled or destroyed. The Anshan iron works was temporarily shut down owing to the removal of a small amount of key machinery, and the by-product plant connected to it had been stripped of over half its equipment, reducing capacity by 70 percent. Damage to other acid and alkali plants was minimal; Pauley reported that they could be restored to full capacity at little expense. In 1946 the Fushun oil-shale plant produced only 9,500 and the Anshan iron works 2,500 tons of ammonium sulfate, while the Dairen plant was said to be largely destroyed. By 1947 production of caustic soda, once sufficient to supply the whole region, was nil. The capacity of the Kirin carbide plant and, as a result, the rubber industry was down 95 percent, explosives were down 75 percent, industrial gases 60 percent, and other chemicals 50 percent.[95]

Assessment of the liquid fuel industry was similarly hampered by lack of access to several plants, but Pauley concluded that this enterprise had no future in any case. Total capacity, which exceeded six million barrels per year by the end of the war, had been reduced by 75 percent. While several plants could be put back in operation, Pauley's study showed that this was economically unwise. The cost of making one barrel of gasoline from coal, based on operating expenses alone (as high as $4.62), was several times that of producing the same amount at the Dairen refinery (only $0.54). The cost of gasoline from shale oil ($0.65 per barrel) was only slightly higher than that of refined gasoline, but this figure is misleadingly low because the expense of removing the shale was charged to coal mining operations. There was, in sum, little prospect for reviving any of the synthetic gasoline factories. And since the largest petroleum refinery, at Dairen, remained in Soviet hands, while the two smaller plants had been stripped clean, the future of liquid fuels in Manchuria was dim.[96]

The other portion of China that received the mixed blessing of Japanese governance for a prolonged period was the island of Taiwan, which had been ceded at the close of the Sino-Japanese War in 1895. Though they undertook no program of industrialization on the scale adopted in Manchuria, the Japanese did build several modern enterprises on the island, including a number of chemical

[94] Pauley, *Japanese Assets*, p. 37.

[95] On acid and alkali plants, see *ibid.*, pp. 185–187, App. 10, 20-C-1; on Fushun, see *ibid.*, p. 165; on Anshan and Penhsihu, see *ibid.*, pp. 101–104, App. 5, 2-A-1; on chemical fertilizer, see Chou Ch'ang-yün, "T'u-jang fei-liao-hsüeh" (cit. n. 44), p. 22; on caustic soda, see Yü Jên-chün, "Tien-chieh kung-yeh" (cit. n. 28), p. 5; on other plants, see Pauley, *Japanese Assets*, pp. 41–42.

[96] Pauley, *Japanese Assets*, pp. 41, 165–167, 174, 182–183.

factories. Most of these survived the war and formed the basis of industrial corporations set up and run by the Chinese government.

The greatest success was in alcohol production. Taiwan is the home of *Saccharum officinarum,* commonly called sugarcane, and under Japanese guidance the island emerged as the world's fourth leading producer of refined sugar. Attached to the sugar refineries were at least thirty distilleries that produced ethyl alcohol from molasses. By the end of the war these plants had a combined daily capacity of 68,000 gallons, a figure far in excess of that achieved by the Chinese Nationalists despite their heavy investment in this industry.[97]

The success of Taiwan's agriculture depended on large inputs of fertilizer, consumption of which exceeded 300,000 tons per year during the colonial period. While most chemical fertilizer was imported, the Japanese also built four plants in Taiwan, two for calcium cyanamide and two for superphosphates, with a combined output of 33,000 tons. These plants were badly damaged by Allied bombing and closed before the end of the war, but they reopened in 1946 as part of the National Taiwan Fertilizer Corporation and reached full production the following year. In 1949 the provincial government set up an ammonium sulfate factory in Kaohsiung. Three of these factories made their own sulfuric acid, the phosphate plants using lead chambers, and the ammonium sulfate plant by the contact method.[98]

The salt fields of southern Taiwan, like those near Tangku, offered an excellent site for the manufacture of soda. The Japanese built three electrolysis factories, in Kaohsiung, Tainan, and Pingan, making the island self-sufficient in caustic soda. In May 1946 these plants were brought together to form the Taiwan Soda Corporation, operated jointly by the national and provincial governments. In 1948 production of caustic soda reached 4,800 tons.[99]

Finally, Taiwan enjoyed a modest oil industry. After petroleum was discovered in Miao-li County in 1861, sporadic attempts were made to tap this source. Pressed by the demands of military expansion, the Japanese undertook extensive drilling operations, which yielded a one-year high of six million gallons of crude oil by the end of the war. The Japanese navy tried to construct a refinery at Kaohsiung, but American bombing interrupted this work. In May 1946 the China Petroleum Company was set up to take charge of oil production at Kaohsiung and throughout the country. This company continued to pump oil from the Miao-li fields and by the spring of 1947 succeeded in bringing the Kaohsiung refinery into operation, although the daily capacity of this plant reached only 7,000 barrels.[100]

Despite its many problems, by 1949 the Chinese chemical industry had made a substantial recovery. Twelve sulfuric acid plants—ten in China proper, one each in Manchuria and Taiwan—produced 100,000 tons annually, roughly balancing consumption. Yungli turned out 40,000 tons of soda ash in 1948, although demand remained high and imports of expensive foreign soda continued. The yearly output of caustic soda returned to the level, around 7,000 tons, achieved in China proper before the war. Manufacture of ethyl alcohol exceeded 31 million

[97] Li Ch'iao-p'ing, *Chung-kuo hua-hsüeh shih* (cit. n. 28), pp. 401, 404.
[98] *Ibid.*, pp. 372, 431–437.
[99] *Ibid.*, p. 376.
[100] *Ibid.*, pp. 385–388.

gallons annually, three times the peak rate of Free China. Production of refined petroleum products approached 20 million gallons, a 50 percent increase over the combined wartime output of the Manchurian and Kansu refineries. The chemical fertilizer industry fared less well: in 1949 production of ammonium sulfate was only 27,000 tons, all made at Hsiehchiatien, versus the 1941 peak of 227,000 tons, most of which had come from the Japanese plant at Dairen.[101]

Whatever the achievements, this was the last act on a stage that itself had already collapsed. Amidst the spreading civil war, most factories operated sporadically, if at all. In the absence of a stable and secure political framework, no new technologies were introduced and no new enterprises begun. By the middle of 1949 most areas of China were under Communist control, while the Nationalist Government and army were in flight. The fate of the Chinese chemical industry was in the hands of the new regime.

POSTSCRIPT: THE CHEMICAL INDUSTRY AFTER 1949

This study ends in 1949; no attempt has been made to examine in detail the chemical industry under the People's Republic. Implicit in the efforts of the republican era, however, was the expectation that the knowledge and skills derived from this earlier experience and the physical base laid down would contribute to the later growth of the Chinese economy. Even a cursory glance at the first decade of Communist rule suggests that this was indeed the case.

After an initial period of recovery, in 1953 Peking launched its first Five-Year Plan, the purpose of which was to expand China's heavy industry following the Stalinist model and with the aid of Soviet capital and advice. Prior to their departure in 1960, Russian engineers oversaw the completion of 130 industrial plants, including several in the chemical sector, built on the foundations of factories erected before 1949. Several large plants were set up in Kirin, which became the center of the Chinese chemical industry. The big push to increase production of chemical fertilizer included measures to double the capacity of the ammonium sulfate plants at Dairen and Hsiehchiatien. A large refinery was built in Lanchow to treat petroleum from the Yumen fields. Other chemical factories were built in various parts of the country.[102]

The goal of the plan was to spur rapid growth in basic industries through direct investment from above, and it worked. The portion of fixed investment committed to industry rose from 36 percent in 1952 to 52 percent in 1957, while producer goods received between 76 and 88 percent of the industrial share. As a result of this input, production in the modern industrial sector doubled in the years from 1952 to 1957, while the output, measured by value, of seventeen leading producer goods increased by an average of 165 percent. By comparison, the increase in production of caustic soda (125 percent) was below, soda ash (164 percent) equal

[101] On sulfuric acid, see Shên Tsêng-tso, "Liu-suan kung-yeh chi" (cit. n. 36), p. 11; on soda ash, see Ch'ên Chên and Yao Lo, eds., *Kung-yeh-shih tsŭ-liao* (cit. n. 11), p. 519; on caustic soda, see Yü Jên-chün, "Tien-chieh kung-yeh" (cit. n. 28), p. 4; on fertilizer, see Jung-chao Liu, *China's Fertilizer Economy* (cit. n. 42), pp. 7, 129; and Ch'ên Chên and Yao Lo, eds., *Kung-yeh-shih tsŭ-liao* (cit. n. 11), p. 519. For other figures, see Cheng Yu-kwei, *Foreign Trade* (cit. n. 1), p. 267.

[102] On ammonium sulfate plants, see Jung-chao Liu, *China's Fertilizer Economy* (cit. n. 42), pp. 10–14, 128–130; for other details, see Nai-ruenn Chen and Walter Galenson, *The Chinese Economy Under Communism* (Chicago: Aldine, 1969), pp. 114–116.

Table 8. Chemical production in Manchuria and China proper (1,000 tons)

	Pre-1949 peak	1947–1949	1952	1953	1954	1955	1956	1957
Soda ash	110	40	192	223	309	405	476	506
Caustic soda	20	7	79	88	115	137	156	198
Sulfuric acid	—	100	190	260	344	375	517	632
Ammonium sulfate	227	27	181	226	298	332	532	631

SOURCES: For period through 1949: Pauley, *Japanese Assets,* p. 201. For 1952–1957, for ammonium sulfate: Jung-chao Liu, *China's Fertilizer Economy* (Chicago: Aldine, 1970), pp. 12–13; for other chemicals: Liu Ta-chung and Yeh Kung-chia, *The Economy of the Chinese Mainland* (Princeton, N.J.: Princeton Univ. Press, 1965), p. 454.

to, and sulfuric acid (233 percent) and ammonium sulfate (249 percent) above the average. Table 8 shows the annual output of these chemicals at the pre-1949 peak, for the years just before 1949, and for the period of the first Five-Year Plan.[103]

APPENDIX: GLOSSARY OF CHINESE NAMES

Academy of Current Affairs
時務學堂
Ch'ên Kuang-fu
陳光甫
China Alcohol Factory
中國酒精廠
China Institute for Economic and Statistical Research
經濟統計研究所
China Petroleum Company
中國石油公司
Chinese Industrial Chemical Research Institute
中華工業化學研究所
Chinese Society of Chemical Industry
中華化學工業會
Ching-hsing Mining Bureau
井陘礦務局
Chiu-ta Refined Salt Company
久大精鹽工廠
Chou Tso-min
周作民
Fan Ching-shêng
范靜生
Fan Hsü-tung
范旭東
Fan Jui
范銳
Fan Yüan-lien
范源濂
Golden Sea Research Institute of Chemical Industry
黃海化學工業研究社
Hou Chih-pên
侯致本
Hou Tê-pang
侯德榜
Hsiehchiatien
卸甲甸
Hsien-yang Alcohol Factory
咸陽酒精廠
Hsüeh Chi-ming
薛濟明
International Dispensary
五洲固本造藥廠
K'ai-ch'êng Acid Company
開城製酸公司
Kansu Petroleum Bureau
甘肅油礦局
Kiangnan Acetic Acid Company
江南醋酸廠

[103] Chen and Galenson, *Chinese Economy,* pp. 50, 56, 62.

Kiangnan Arsenal
江南製造局
Kiangsu Chemical Works (Major Brothers), Ltd.
江蘇藥水廠
Kincheng Bank
金城銀行
Kwangtung Provincial Caustic Soda Factory
廣東省營苛性鈉廠
Kwangtung Provincial Fertilizer Factory
廣東省營肥田料廠
Kwangtung Provincial Sugar Factory
廣東省營糖廠
Kwangtung Provincial Sulfuric Acid Factory
廣東省營硫酸廠
Leo Shoo-tze
劉樹杞
Li-chung Acid Manufacturing Company
利中製酸公司
Liang-Kwang Provincial Sulfuric Acid Factory
兩廣省辦硫酸廠
Liu Ta-chün
劉大鈞
Lung-hua Powder Plant
龍華火藥廠
Nankai University Institute of Applied Chemistry
南開大學應用化學研究所
National Bureau of Industrial Research
中央工業試驗所
National Resources Commission
資源委員會
National Taiwan Fertilizer Corporation
國營台灣肥料公司
Pohai Chemical Works
渤海化學工業公司
Progressive Party
進步黨
P'u-i Sugar Factory
溥益糖廠
Shanghai Commercial and Savings Bank
上海商業銀行
Sinyuan Fuels Research Laboratory
沁園燃料研究室
Taiwan Soda Corporation
國省合營台灣鹼業公司
Tung-li Oil Works
動力油料廠
Tzuliuching
自流井
T'ien-ch'u Monosodium Glutamate Factory
天廚味精廠
T'ien-li Nitrogen Gas Company
天利淡氣製品公司
T'ien-yüan Electrochemical Factory
天原電化廠
West China Academy of Sciences
中國西部科學院
Wu Ch'êng-lo
吳承洛
Wu Yün-ch'u
吳蘊初
Wutungchiao
五通橋
Yenchang
延長
Yungli Chemical Industry Company
永利化學工業公司
Yungli Soda Manufacturing Company
永利製鹼公司