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Nitrogen: Its Fixation, Its Uses in Peace and War

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NITROGEN: ITS FIXATION, ITS USES IN  
PEACE AND WAR <sup>1</sup>

SUMMARY

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THE nitrogen fixation plants built by the government during the great war at a cost of about one hundred million dollars, to supply materials needed for making explosives and poisonous gases, have been idle since the Armistice. These plants could be utilized, whether sold to private corporations or operated by the government, for the fixation of atmospheric nitrogen for industrial and agricultural purposes, and thus greatly

<sup>1</sup> The inquiries which have led to this paper were begun while the author was in charge of the chemical division of the United States Tariff Commission. In the preparation of the paper Mr. C. R. DeLong, of the present staff of the Tariff Commission, has given invaluable aid. He has contributed not only to the statistical material and its verification, but to the discussion of the larger questions of chemical progress and industrial policy.

increase the supply of nitrogen compounds needed in the industries, and stimulate the production of food through supplying nitrogen for the manufacture of fertilizer. The present anomalous situation in the government plants gives occasion for a survey of the remarkable chemical developments of recent years and of their importance for war and for peace.

Nitrogen, tho the most important element needed for an adequate supply of fertilizer, is not the only one essential. Two others are also important: potash and phosphoric acid. All must be chemically combined in such a way as to be available as plant food.

Before the outbreak of the war potash was obtained entirely from Germany, at a price maintained substantially above the cost of production by a German monopoly. Exports from Germany ceased early in 1915, and prices in the United States promptly rose to about ten times normal. Existing stocks were thereafter largely diverted to chemical uses, and relatively insignificant amounts were used in fertilizer from 1916 up to and including 1919. In the United States, England, Chile, and Japan potash is now obtained from many different geological and botanical sources, and is being recovered as a by-product of several industries. Altho many of these new enterprises will probably not survive competition with the German and the Alsatian mines, because of inherent geological and geographical disadvantages, some, at least, will recover potash, as a by-product, at a low cost. Furthermore, altho the deposits in Alsace are not so extensive as the vast potash deposits near Stasfurt, Germany, they are as good in quality, can be mined as cheaply, and are ample in quantity to supply the total needs of the world for a century. The German monopolistic control over prices is definitely broken, and the American consumer will benefit thereby.

Phosphoric acid is obtained from phosphates of lime, which are derived either from natural deposits of phosphate rock or from bones of animals by means of treatment with sulphuric acid, this treatment making the phosphate more soluble and therefore more available as plant food. During the war there was no shortage of phosphate rock. Indeed, more than half of the world's supply is normally mined in the United States, and a considerable fraction of the output was, prior to 1914, exported to Germany. The loss of this export market resulted in decreased total output but also in ample supplies and low prices for domestic consumers.

Since sulphuric acid in enormous amounts was required for the manufacture of explosives, much of our supply was diverted from the making of fertilizer to direct war use. However, most manufacturers of fertilizer make the acid they need, and hence this diversion did not result in direct financial loss. But their regular business was disorganized and their customers suffered from the disruption. As a direct result of the war demands for sulphuric acid the productive capacity for the manufacture of sulphuric acid in the United States is now more than twice what it was in 1914. This new productive capacity can be utilized completely only through a great increase in the consumption of acid phosphate. Moreover, the war stimulus to the mining of pyrites and sulphur has greatly increased the domestic supply of the raw materials (particularly sulphur) for the making of sulphuric acid. Before the war sulphuric acid was made chiefly from Spanish pyrites. The scarcity of shipping and the doubling of the demand for sulphuric acid necessitated a shift to the use of American sulphur as the principal raw material. There are many indications that the greatly enlarged American sulphur industry will retain its new outlet and that the

competitive struggle between the producers of domestic sulphur and of Spanish pyrites, which may confidently be expected as soon as ocean shipping rates become normal, will make sulphuric acid available to the manufacturers of fertilizer in large amounts and at low prices.

Most important, however, are the changes affecting the fertilizer industry which have occurred in the development in nitrogen production. It is with this development that the present paper is primarily concerned.

Nitrogen in chemically combined form in the soil is essential to the growth of all plants. Indeed the limiting factor in the fertility of soil is commonly a deficiency in nitrogen, which is normally the most expensive ingredient per unit in fertilizer. Owing to the chemical instability of its compounds, and the relatively large requirements of plant growth, nitrogen is lost from the soil more rapidly than either potash or phosphate, and must be systematically restored.

Furthermore, in addition to the vital importance of nitrogen in the fertilizer industry, its compounds play an essential rôle in many chemical industries, and there will continue to be competition between the agricultural and the industrial demand for this element and its compounds.

## I. CLASSIFICATION AND USES OF NITROGEN COMPOUNDS

The many hundreds of nitrogen compounds of agricultural or industrial importance may be conveniently considered in four groups:<sup>1</sup> (1) proteins; (2) nitrates and nitric acid and derivatives thereof; (3) ammonia and its compounds and derivatives; (4) cyanides and their compounds and derivatives.

<sup>1</sup> This classification is not rigidly exact, because there are a relatively small number of compounds which may not fit into any of these classes, such as, pyridin; and a few may fit into more than one class, for example, ammonium nitrate.

1. Proteins, as is well known, include the principal forms in which nitrogen exists in the bodies of plants and animals. Wool, silk and leather are proteins. Of even greater importance are the digestible proteins, which are present in flesh, in grains and in many vegetables and are an essential constituent of the food of all animals. The fertilizer industry utilizes much waste protein material which is unsuitable for food because of its unsanitary quality.

2. Crude sodium nitrate is one of the most important raw materials for commercial fertilizer.

Nitrates, or nitric acid, are essential for the manufacture of old-fashioned black gunpowder, modern smokeless powder, dynamite, mercury fulminate and other substances used as primers, the high explosive bursting charges for shells, torpedoes and depth bombs, such as trinitrotoluene (T.N.T.), picric acid, ammonium picrate, and ammonium nitrate, and nitro-starch used in hand grenades. Altho there are explosive substances which do not require nitric acid for their manufacture, none of them was utilized to any appreciable extent in the recent war, because of serious disadvantages which precluded their use. Nitric acid or a nitrate is indispensable for the manufacture of each and every explosive of any military value and is important in pyrotechnic signals. An adequate supply of nitrates or nitric acid is therefore an essential part of any military program, should it be necessary, alas, to consider military requirements hereafter.

Nitric acid (or nitrates) is also required for the manufacture of potassium nitrate and of pyroxylin plastics such as celluloid, certain varieties of moving picture films, most dyes, and many other products derived from coal tar, as well as for scores of minor uses. Considerable amounts are also required for the manufacture of sulphuric acid.

3. Salts of ammonia, especially the sulphate, are much used in fertilizer, this use being quantitatively much larger during times of peace than all the other uses of ammonia put together.

Ammonia is utilized in many industrial operations, as for example in the manufacture of artificial ice. Artificial refrigeration by means of ammonia within the last few years has well-nigh revolutionized the distribution of food. Its use is already common in some industries in which the product must be kept chilled during manufacture. The artificial cooling, during the summer, of hotels, theaters, offices, and factories, and even homes, may become common within a decade or two. Artificial cooling of buildings in summer is more expensive than their heating in winter. Complicated machinery and skilled attention are required. These factors are a serious obstacle to the introduction of the process in homes but not prohibitive in hotels, theaters, or factories.

Other salts of ammonia, particularly the nitrate and picrate salts, are extensively used as high explosive shell fillers in warfare and in mining operations. Ammonia is also used as a household cleansing agent and for many purposes in medicine and in the chemical industries. A method has recently been developed for converting ammonia into nitric acid. This method has reached its highest development in Germany and during the war it enabled the Germans to make explosives from ammonia rather than from Chilean sodium nitrate.

4. Cyanides are not used as an ingredient in fertilizers. They are used, in the "cyanide process," for extracting gold from its ores. The discovery of this process in 1887 has been mainly responsible for a four-fold increase in the annual output of fresh gold. Cyanide is also largely used in the electroplating of metals,

especially gold and silver, in the case-hardening of steel, and in the manufacture of certain pigments; and furthermore in the destruction of insect pests and vermin, particularly in the fumigation of citrous fruit trees. At one time cyanides were also in considerable demand for use in poison gas warfare, but they did not prove to be as effective as several other substances. If obtainable cheaply enough, they may serve as a source of ammonia, formic acid, and oxalic acid. At the present time the amount of cyanides used is only a small per cent of the consumption of nitrates or ammonia.

## II. SOURCES OF FIXED NITROGEN

Considerable amounts of nitrogenous materials of organic origin such as manure, cottonseed meal, dried blood, tankage, leather scrap, and tobacco stems are used as fertilizer. But since the nitrogen in these materials is all derived directly or indirectly from the soil its return to the soil is merely a partial repayment of nitrogen already removed therefrom. Altho the maximum utilization of these materials is important, considerable losses are inevitable and must be made up from other sources. Fish scrap and kelp derived from the sea furnish a net gain of nitrogen to the land, but on a scale insufficient to compensate for inevitable losses. It is, therefore, apparent that in order to meet the urgent demands for nitrogen needed to maintain the fertility of our soils, we must turn to sources other than these waste materials of animal or plant origin.

Supplies of chemically combined nitrogen necessary to maintain the fertility of the soil and to meet the industrial demands are obtained almost entirely from three sources: sodium nitrate <sup>1</sup> mined in Chile, ammonia

<sup>1</sup> Also called "niter" or "Chilean saltpeter." True "saltpeter" is potassium nitrate.



obtained as a by-product in making coke and illuminating gas from coal, and nitrogen from the air, which may be made available either by chemical operations or by legumes. It is the development and expansion of these sources of nitrogen on which we must depend for our future requirements of fixed nitrogen for agricultural, industrial and military purposes.

### *Chilean Nitrate*

Nitrates are found naturally, in amounts which warrant extraction on a commercial scale, in only two countries in the world, Chile and India. Potassium nitrate is extracted from the soil of India for sale and export, but in amounts which are insignificant in comparison with the production of sodium nitrate in Chile. The following table shows the situation:

CHILEAN AND INDIAN NITRATE STATISTICS  
(Short tons)

Year	Chile					India
	Production <sup>1</sup>		Exports of nitrate of soda <sup>2</sup>	Revenue from export duty <sup>2</sup>	Per cent of total revenue of Chile <sup>2</sup>	Exports of saltpeter—potassium nitrate <sup>3</sup>
	As nitrate of soda	Equivalent of nitrogen on basis of 15.65 %				
1913	3,055,808	478,234	3,015,479	\$32,896,947	48	17,062
1914	2,715,047	424,905	2,034,374	23,751,756	52	15,998
1915	1,935,143	302,850	2,227,599	24,564,128	59	23,442
1916	3,210,008	502,366	3,280,660	36,599,903	59	27,158
1917	3,319,918	519,567	3,055,180	38,892,824	50	28,860
1918	3,170,106	496,122	3,289,325	40,333,936	44	26,296
1919 <sup>4</sup>	556,817	87,142	167,328	.....	..	....

<sup>1</sup> For 1913–16 inclusive from Association Salitrera de Propaganda; 1917–19, from publications of International Institute of Agriculture, Rome, Italy.

<sup>2</sup> From Caliche, Organo del Instituto Cientifico E Industrial del salitre, Santiago, Chile, August, 1919.

<sup>3</sup> From publications of International Institute of Agriculture, Rome, Italy.

<sup>4</sup> First three months.

CONSUMPTION OF CHILEAN NITRATE BY COUNTRIES IN 1913<sup>1</sup>

Country	Per cent of total	Country	Per cent of total
Germany.....	32.6	Italy.....	2.0
United States.....	23.0	Egypt.....	1.0
France.....	12.8	Spain.....	.5
Belgium.....	12.5	Austria Hungary.....	.3
Holland.....	6.4	Denmark.....	.4
United Kingdom.....	5.0	Others.....	3.5

These Chilean nitrate deposits are located in a district where rain rarely falls and no vegetation grows. They are found near the surface and can be dug from open pits. The refining operations consist of extraction from the earthy material by solution in water and purification by recrystallization. All the water needed for the refining operations and for the life of the miners must be brought from a distance. The industry employs on an average in normal times about 55,000 workmen.

The extraction of nitrate in Chile began about 1830, and has had a steady growth. The annual output had attained to approximately 3,000,000 tons at the outbreak of the war. About two thirds of this was used directly for fertilizer and one third for industrial chemical purposes including the manufacture of explosives.

At the outbreak of the war a German fleet of five cruisers under Admiral von Spee, stationed off the coast of Chile, dominated the South Pacific ocean and entirely prevented any shipments of sodium nitrate. On November 1, 1914, Admiral Craddock, with a fleet of three ships, altho hopelessly outclassed in gun power, attacked the Germans and sacrificed his ships in a vain effort to open the path for nitrates to England and to

<sup>1</sup> Calculated from statistics taken from *Production et Consommation des Engrais Chimiques dans le Monde*, Institut International d'Agriculture, Rome, Italy.

the United States. A superior English fleet under Admiral Sturdee was soon despatched to the scene and on December 8, 1914 met and sank the Germans in the battle of the Falkland Islands, thus making it possible for exports of nitrate from Chile to be resumed.

In the meantime, the mines and refineries in Chile finding their market cut off had curtailed their output. Thus the output of the most important raw material for the manufacture of military explosives showed a marked decrease in the first six months after the outbreak of war.

The Chilean government imposes an export duty amounting to \$11.19 per net ton (3.38 pesos gold per 100 kilos) on all sodium nitrate exported. This tax normally yields the Chilean government about \$30,000,000 per year, or approximately half of the total revenue, and in addition the government derives revenue from the sale of the lands.<sup>1</sup> It is obvious that if the methods for making nitrates from the air should succeed sufficiently to threaten seriously the Chilean industry, the government of Chile might be forced to reduce or entirely eliminate the export tax in order to maintain the industry on which the prosperity of the country largely depends. The possibility of a reduction or elimination of the export tax on Chilean nitrate compels a more conservative judgment on the prospects of the new methods for obtaining nitrogen from the air. However, it is hardly probable that the tax will be reduced unless this action is forced on the Chilean government by the development of the newer methods to such an extent that their competition is sharply felt by the nitrate industry.

Estimates of the reserves of nitrate in Chile vary greatly, and indeed no very accurate estimate is possible

<sup>1</sup> Incidentally it may be worth mentioning that almost the total world's supply of iodine (about two million pounds per year) is obtained as a by-product of this industry and yields the government nearly half a million dollars as export duty.

because of the local variation in the thickness and richness of the nitrate deposits and the incompleteness of the surveys. An official report made in 1913 to the Chilean government by the Inspector-General of Nitrate Deposits concludes with the statement: . . . "There is no fear of the Chilean nitrate deposits being exhausted for 200 years."

### *Coal*

Until very recently commercial supplies of ammonia and its compounds were obtained almost entirely as a by-product of the coking of soft coal. Ammonia is obtained in the United States in part from city gas plants but mainly as a by-product of coke ovens. Relatively insignificant amounts are obtained from other sources such as sewage and garbage disposal plants and the distillation of bones and oil shales. For many years the oil shales of Scotland have yielded about 15 per cent of the British output of ammonia but shales have been little used elsewhere. There are enormous reserves of oil shales in the United States which may in the future yield considerable ammonia in case they are utilized on a large scale as the source of fuel oil. Indeed, the utilization of oil shales on a large scale can hardly be delayed for more than a few decades unless new and very prolific oil fields are discovered. The output of ammonia in the United States during 1918 was equivalent to nearly one hundred thousand tons of pure ammonia. This was marketed chiefly in the form of ammonium sulphate containing 25 per cent of ammonia, the form in which ammonia is commonly used for fertilizer. About one-half (54.0 per cent in 1918 and 43.8 per cent in 1919) of the metallurgical coke produced in the United States is still made in the old-fashioned beehive ovens, which waste all of the by-products — ammonia, benzol, toluol,

coal tar and coal gas. The output of the by-product ovens has been rapidly overhauling the output of the old style beehive oven and it is not unreasonable to expect that within one or two decades the by-products will be saved from all the coke produced in the United States, as has been done in Germany for many years.<sup>1</sup>

PRODUCTION OF BY-PRODUCT AMMONIA IN PRINCIPAL COUNTRIES  
(Short Tons of Ammonium Sulphate)

Country	1913	1914	1915	1916	1917	1918
United States <sup>2</sup> . . .	190,922	181,569	249,049	288,265	326,166	377,913
United Kingdom <sup>3</sup> .	484,532	477,581	477,419	485,747	513,651	484,457
Germany <sup>4</sup> . . . . .	605,163	456,173 <sup>5</sup>	6	6	6	6
France <sup>4</sup> . . . . .	82,121	....	46,297	27,557	37,478	33,069
Japan <sup>4</sup> . . . . .	8,818	17,675	35,080	42,111	63,840	100,799
Canada <sup>4</sup> . . . . .	10,607	8,571	10,448	....	....	....
Italy <sup>4</sup> . . . . .	14,802	15,789	16,203	16,535	9,921	11,023
Australia <sup>4</sup> . . . . .	6,048	6,328	7,168	7,952	....	....
Netherlands <sup>4</sup> . . . .	7,716	5,512	5,512	4,409	....	....
Spain <sup>4</sup> . . . . .	16,535	17,637	18,188	19,841	14,054	....
Russia <sup>4</sup> . . . . .	15,222	18,933	18,056	36,111	....	....
Austria-Hungary <sup>4</sup> .	38,580	38,580	38,580	....	....	....

<sup>1</sup> The following table shows the fraction of the United States output of coke produced in by-product ovens, as compiled by the Geological Survey:

1890 . . . . .	0	1916 . . . . .	35.0
1900 . . . . .	5.3	1917 . . . . .	38.6
1905 . . . . .	10.7	1918 . . . . .	46.0
1910 . . . . .	17.1	1919 . . . . .	56.2
1915 . . . . .	33.8		

In 1919 the output of coke was sharply reduced as compared with 1918 owing to strikes in the steel and coal industries but the reduction was almost entirely in beehive coke, 9,831,000 tons or 32 per cent as compared with a reduction of only 827,000 tons or 3.2 per cent in by-product coke.

<sup>2</sup> From official governmental sources. In computing total for 1913 and 1916, figures published by the Barrett Company, New York, have been used for sulphate of ammonia produced in coal gas and bone carbonizing works.

<sup>3</sup> From Annual Reports of the Alkali Inspector, United Kingdom.

<sup>4</sup> From publications of International Institute of Agriculture, Rome, Italy.

<sup>5</sup> Total sales of members of the Union.

<sup>6</sup> Accurate statistics not available. Published reports do not indicate any increase in the production of by-product ammonia in Germany during the war.

American production has been supplemented by imports on a considerable scale. In 1914 the imports of ammonia were 50 per cent of the domestic production of ammonia. The imports have come almost entirely from Great Britain, which country was the largest exporter of ammonia. When the food supply of Great Britain was threatened by the submarine, export of ammonium sulphate from Great Britain ceased, because the British used this material in the form of fertilizer on their land to stimulate food production as well as for the manufacture of explosives. It is improbable that England will soon forget the importance of raising a larger fraction of her food supply at home or that she will forego the aid of ammonium sulphate in such an endeavor. America can hardly count on receiving ammonia from English coke ovens in the future.

Since ammonia is a by-product of the coke industry, the amount produced from this source will be regulated by the demand for coke and will be little influenced by the price of ammonia, except in so far as a high price for ammonia may hasten the replacement of the beehive oven by the by-product oven. But there is no prospect that the price of ammonia will go so low that it will not be profitable to recover it from existing by-product ovens. In the past whenever during periods of business depression there has been a decreased demand for coke, the beehive ovens have ceased operations rather than the by-product ovens. The growing demand for coal tar arising from the development of the American dye industry should hasten the replacement of beehive coke ovens by by-product ovens and thus yield more by-product ammonia.

The newer synthetic method for producing ammonia, to be discussed presently, will not decrease the output of ammonia from coal. If the price of ammonia is

lowered through competition, the operator of a coke oven will sell his ammonia for whatever it will bring, and the price of the coke or other by-products will have to be sufficiently high to keep the plants in operation. The economic success of the newer processes is therefore not dependent on an ability to undersell by-product ammonia. These methods can only succeed if the demand is great enough to absorb the total output of the by-product ammonia and still leave a large demand at a price sufficient to maintain the new synthetic industry.

### *Air*

The air contains an inexhaustible supply of nitrogen, approximately twelve pounds to every square inch of the earth's surface. Free atmospheric nitrogen is comparatively inert chemically, so that it is directly available to none of our staple crops except the legumes and can only be made available for fertilizer or industrial uses by special chemical processes. Nitrogen is absorbed in the soil to some extent under favorable conditions by bacterial action. This absorption is carried out more effectively and in much larger amounts by those bacteria having a symbiotic relationship with leguminous plants. The legumes, including the many varieties of peas, beans, clover and alfalfa, utilize in their growth the nitrogen absorbed by the bacteria attached to their roots. The soil is then enriched by the plowing in of the crop or by feeding the crop to cattle and by deposition of the manure on the land. This ability of the legumes to absorb nitrogen from the air is an important reason for the rotation of crops commonly practiced by good farmers.

### III. THE FIXATION OF ATMOSPHERIC NITROGEN BY CHEMICAL PROCESSES

In addition to the biological process of recovering nitrogen from the air there are at least four chemical processes for the fixation of atmospheric nitrogen which have been developed to the point of large scale factory operation.

#### *Arc Process*

The earliest of these to be developed successfully is the direct combination of nitrogen and oxygen of the air by means of an electric arc, resulting in the formation of nitric oxide which may then be converted into nitric acid by combination with water and with more atmospheric oxygen. For use as fertilizer the acid so made is commonly allowed to act on limestone producing calcium nitrate or nitrate of lime. This material unfortunately has a tendency to absorb water from the air, a characteristic which makes it necessary to ship it in sealed containers instead of in bulk or in bags. The tendency to absorb water also seriously interferes with its distribution on the land as the machinery commonly used in the United States will operate successfully only when using dry powders. However this difficulty has recently been lessened by a change in the method of manufacture which yields a product containing excess of lime.

The direct combination of oxygen and nitrogen requires very high temperatures, such as are attained only in the electric arc, and very large amounts of energy must be supplied at this high temperature in order to make the combination possible. Moreover, in none of the furnaces has it been possible to secure a yield of more than 2 per cent of nitric oxide in the air issuing from the



furnace and  $1\frac{1}{4}$  to  $1\frac{1}{2}$  per cent is the usual yield. The large excess of air which escapes chemical combination must be heated to the temperature of the arc. This process therefore necessarily requires large amounts of power in proportion to the yield of fixed nitrogen, estimated at 8.4 kilowatt-years per metric ton of fixed nitrogen. It is stated that only 3 or 4 per cent of the electrical energy is actually utilized in the union of nitrogen and oxygen. An expensive equipment is also required to remove the oxides of nitrogen from the large excess of air and to produce saleable products. Nitric acid is the primary saleable product of the arc process, from which nitrates for fertilizer can be made only by the use of additional materials, equipment and labor, and therefore at a cost above that of nitric acid. Conversely, nitrates are the primary and therefore the cheapest product of the Chilean industry, and nitric acid is a secondary product, whose production entails additional cost. The arc process, even in localities where it is dependent on coal for power, may perhaps be able to produce its primary product, nitric acid, in competition with that manufactured from Chilean nitrate.<sup>1</sup> But the arc process, except in places where power is unusually cheap, cannot produce its secondary product, nitrates for fertilizer, in competition with the primary product of the Chilean industry, sodium nitrate. On the other hand, the arc process has many advantages over the other methods to be presently described. The only raw materials required for nitric acid are air and water, available for the mere cost of pumping. If the product is to be sold as fertilizer, limestone is also required but this is one of the cheapest of minerals. The furnaces have been so perfected that they operate automatically

<sup>1</sup> See Final Report of Nitrogen Products Committee, Ministry of Munitions of War (British), par. 190, 202.

for indefinite periods, requiring no direct labor, very little supervision, and repairs only at long intervals. This process yields nitric acid as its primary product, which has certain advantages both from a military and agricultural point of view. Unfortunately nitric acid is more difficult and expensive to ship than ammonia, which is the primary product of most of the other processes.

The direct process has been financially profitable, and has had a substantial growth in Norway and some development in the Alps. Abundant water power is available in Norway at an exceptionally low price, owing to the fact that the natural conditions permit the development of water power with relatively little capital investment for dams, reservoirs, and other engineering developments; and because there are no highly developed industrial centers at hand containing large consumers of power who are able and willing to pay a higher price. For these reasons power is available for the fixation of nitrogen in Norway at a price or cost of only about one-third (\$4.30 to \$10 per kilowatt-year) of the lowest price at which power can be purchased at Niagara Falls.

Three other small factories to operate the direct arc process have been erected in Europe — one in France, one in Italy, one in Austria. These have apparently not been so successful as the Norwegian plants. A plant erected in North Carolina was abandoned because it proved to be more profitable to sell the power for other uses. A small plant (making sodium nitrite for the dye industry) has been built recently near Tacoma, Wash., by the American Nitrogen Products Company, utilizing "off-peak" power during the part of the day when demand for lighting and power is low. Such a surplus of power, if not utilized, will be lost, and may therefore be

sold at a low figure. Water which goes over the dam at two o'clock in the morning instead of through the water turbines is permanently lost. As the generating machinery and distributing system of a company supplying power to a city must be constructed on a scale large enough to carry the maximum load during any hour of the entire year, a large surplus of power may be available during a considerable fraction of the time. Since the utilization of the machinery during "off-peak" periods involves no extra interest or overhead charges, and in the case of water power plants even no extra charge for fuel, the "off-peak" power can be sold at very low rates. The arc nitrogen process has certain advantages for utilizing this "off-peak" power because very little labor is required and the furnaces can be quickly started or stopped without serious difficulties. Capital charges on idle plant constitute the most serious obstacle to the use of "off-peak" power in this case.

### *Cyanamid Process*

Another process is based upon the fact that calcium carbide at a temperature of about  $1200^{\circ}\text{C}$ . will chemically combine with nitrogen gas to form calcium cyanamid, which may be used directly as fertilizer or may be converted into ammonia by treatment with steam and alkali under pressure. The fundamental raw materials are limestone, coal, water and air, together with electrical power. The first operations are to convert the coal into coke and burn the limestone to quicklime. The lime and coke are then mixed and heated to a high temperature in an electric furnace, thereby forming calcium carbide. This carbide must be ground to a very fine powder and transferred to another furnace where it is changed into cyanamid by combination with nitrogen.

The nitrogen used is obtained from air, but must be freed from oxygen. This separation is best accomplished by the liquifaction of the air, followed by fractional distillation. The chemical combination of the carbide and nitrogen must be started by heating the carbide locally to a temperature of about  $1200^{\circ}\text{C}$ ., whereupon the reaction begins. The external power may then be turned off because the heat produced by the reaction itself is sufficient to raise the remainder to the desired temperature. The crude calcium cyanamid thus produced requires only to be ground and treated with a little water and oil to prepare it for use as fertilizer or in the manufacture of mixed fertilizers. The cyanamid may also be used for the manufacture of ammonia by treatment with dilute alkali and steam under pressure. By fusion with salt it yields a crude cyanide which is, however, pure enough for use in gold recovery. By still other chemical processes it yields urea which is used in the manufacture of celluloid and as a drug. As compared with the arc process the cyanamid process has the great advantage that the power required is only about one-fourth as great in proportion to the weight of nitrogen fixed (1.97 to 2.30 kilowatt-years<sup>1</sup> per metric ton of fixed nitrogen). On the other hand, the cyanamid process requires coke for the manufacture of carbide in addition to the limestone, water, and air required by the arc process. It yields nitric acid only indirectly through ammonia by another process to be subsequently described.

The cyanamid process secured its commercial start at about the same date as the arc process and has had a substantial development, particularly in Europe.

Calcium cyanamid may be used directly in fertilizers but there are certain serious objections to its use for such purposes. When used with acid phosphate it will in time

<sup>1</sup> See Final Report of Nitrogen Products Committee, loc. cit., par. 108.

WORLD'S PRODUCTION OF CALCIUM CYANAMID <sup>1</sup>

(Short tons)

Country	1913	1914	1915	1916	1917	Actual production 1918	Productive capacity of works completed or under con- struction 1918
Germany.....	26,455	(39,683)	(551,150)	(551,150)	440,920	330,690	(661,380)
Austria-Hungary..	8,267	(26,455)	(26,455)	(26,455)	26,455	26,455	(33,069)
France.....	8,267	(8,267)	(88,184)	(110,230)	110,230	110,230	(330,690)
Italy.....	16,515	17,147	27,879	27,673	13,558	16,534	(88,184)
Norway	24,372	16,171	27,557	29,111			
Sweden	20,229	(19,841)	(18,037)	19,841	220,460 <sup>2</sup>	220,460 <sup>2</sup>	(220,460) <sup>2</sup>
Switzerland.....	8,267	(8,267)	(13,779)	(32,518)	44,092	44,092	(71,650)
Canada.....	52,910	(63,933)	(63,933)	(63,933)	63,933	63,933	(63,933)
Japan.....	7,716	12,314	33,375	36,885	55,999	55,115	111,999
Totals.....	172,999	(212,079)	(850,351)	(897,797)	975,648	867,509	(1,581,365)
Total calculated as nitrogen <sup>3</sup> ....	31,140	(38,174)	(153,063)	(161,603)	175,617	156,152	(284,646)

produce undesirable chemical reactions which render the phosphate less soluble and therefore less available to plants. It is an unpleasant and irritating material to handle. It is probable that in the future much of the cyanamid produced will be converted into ammonium sulphate or ammonium phosphate, which will then be used in fertilizers instead of the cyanamid itself.

*Haber Process (Direct Synthesis of Ammonia)*

The direct combination of nitrogen and hydrogen in such way as to yield ammonia was developed by the German chemist, F. Haber, and was put into operation in Germany on a commercial scale for the first time in 1913. It requires pure nitrogen and hydrogen as raw materials. The nitrogen may be obtained by the fractional distillation of liquid air or from producer gas.

<sup>1</sup> From Publications of International Institute of Agriculture, Rome, Italy. Figures in parentheses are estimated productive capacity. <sup>2</sup> Norway and Sweden.

<sup>3</sup> Calculated on basis of 18 per cent of nitrogen in calcium cyanamid.

The preparation of the hydrogen of the required degree of purity is one of the most troublesome and expensive parts of the process. Hydrogen may be obtained as a by-product of the electrolytic production of chlorine, but in amounts insufficient to supply an ammonia industry adequate to meet the fertilizer demand.

A mixture of hydrogen and nitrogen may be made by passing a blast of steam and air through red hot coke (heated by a blast of air at intervals), which yields a mixture of hydrogen, nitrogen, carbon monoxide, and carbon dioxide. By a subsequent treatment, too complex to be described here, the carbon monoxide is converted into carbon dioxide, which may be easily removed, leaving a pure mixture of hydrogen and nitrogen.

The pure nitrogen and hydrogen are then subjected to a pressure varying from one hundred to two hundred atmospheres and passed over a suitable catalyst at a temperature of about  $550^{\circ}$  C. Under these conditions chemical combination of the nitrogen and hydrogen to form ammonia occurs to the extent of about 5 per cent of the gases present. The product is then cooled while still under pressure and dissolved in water. After this the uncombined gases are returned to the apparatus and treated a second time. The process evolves sufficient heat to maintain the temperature of the apparatus after it is once started, and this gives it an advantage over all other nitrogen fixation processes in the relatively small amount of power required. The power required is only about 0.4 kilowatt-years per ton of nitrogen fixed, which is about one-twentieth of that required by the arc process, or about one-fifth of that required by the cyanamid process per ton of nitrogen fixed. Its commercial development is therefore not dependent on cheap power. The preparation of the catalyst, the purification of the

gases and the design of an apparatus which would stand the necessary temperatures and pressures required scientific and engineering work of a high order. The successful development of this process ranks as one of the greatest achievements of German industrial chemistry. The primary product of the process is aqua ammonia of a purity far surpassing that yielded by either coke ovens or the cyanamid process. For use in fertilizer it is usually combined with sulphuric acid and sold as ammonium sulphate.

Wilhelm Ostwald, one of the great leaders of German science, has developed a method for the conversion of ammonia into nitric acid. The process consists essentially in passing a mixture of ammonia and air through a platinum gauze maintained at a low red heat, thereby converting the ammonia into nitric oxide which may be readily converted into nitric acid.

The Haber process was perfected and put into commercial operation in Germany in 1913, by the Badische Anilin und Soda Fabrik. The Ostwald process had been developed some years previously, but not operated continuously on a commercial scale and was held in reserve as a military asset. Technically it was successful, but not commercially. The military significance of the combined Haber and Ostwald process cannot be overestimated; it made Germany independent of Chilean nitrate for the manufacture of explosives. The Haber plant was a demonstrated technical and commercial success before the outbreak of the war and the company controlling it is known to have been seeking long term contracts for future delivery outside of Germany in anticipation of enlargement of the plants. After the outbreak of the war these plants were rapidly extended and there can be little question that without them the German army must have suffered defeat not later than 1916

through a shortage of explosives. Moreover, the Haber process has great possibilities along a line quite different. Recent work has indicated very clearly that a combination of the Haber process and the Solvay soda process will be of great benefit to both. To explain in detail the benefits of this combination would require an elaborate exposition of the chemistry of both of these processes, and thus be outside the scope of this paper. It need merely be said that these two processes are to a considerable degree complementary. A waste product of each process can be utilized in the other in the place of a material that must otherwise be especially prepared or purchased for the purpose with the result that when operated together both are simplified and cheapened. The combination process requires only air, coke, water, and salt as raw materials; and yields soda, ammonium chloride, and oxygen as products—the ammonium chloride being used for fertilizer instead of ammonium sulphate, as was originally done in Haber plants.

Since soda ranks second only to sulphuric acid among all chemicals in magnitude of output (1,390,628 short

PRODUCTION OF AMMONIA BY HABER PROCESS <sup>1</sup>

Production in short tons

Year	Ammonium sulphate	Calculated as nitrogen <sup>2</sup>
1913.....	33,000	7,000
1914.....	66,000	14,000
1915 <sup>3</sup> .....	165,000	34,000
1916.....	331,000	68,000
1917.....	551,000	113,000
1918 <sup>4</sup> .....	.....	(215,000)

<sup>1</sup> From Frankfurter Handelsblatt, May 29, 1916. Published in Final Report of Nitrogen Products Committee, Ministry of Munitions of War, Great Britain.

<sup>2</sup> Calculated on basis of 20.58 per cent of nitrogen in ammonium sulphate.

<sup>3</sup> Rate of production by the middle of 1915.

<sup>4</sup> Estimate from private sources.



tons in the United States in 1918) and fundamental importance, the combination of the two processes places the synthetic production of ammonia on a new and much more promising basis. Indeed this may well prove to be the most significant development in industrial chemistry of the present decade.

### *Cyanide Process*

The only other process which merits discussion is the Bucher process, which depends upon the fact that when soda, carbon, and iron are intimately mixed and heated to a red heat in the presence of nitrogen gas the nitrogen is rapidly absorbed, resulting in the formation of sodium cyanide mixed with the unchanged iron. The iron takes no direct part in the reaction but the reaction will not occur with any useful speed in the absence of iron. Although considerable difficulty has been encountered in the operation of this process, it has been developed on a commercial scale so recently that experience with it is very brief but the best available information indicates that the difficulties are not fundamental but can be surmounted by changes in detail of design. The process appears to be the most rational method known for the manufacture of cyanides. Its development up to the limits of the cyanide market may be predicted.

There is also a possibility that this process may produce sodium cyanide at a cost low enough to make it a suitable raw material for manufacture of many other chemicals now made by quite different methods. If sodium cyanide is steamed, it yields ammonia and sodium formate. Sodium formate in turn will serve for the manufacture of formic acid, for which a market of many million pounds per year could easily be developed if its price could be lowered substantially. Sodium formate

may also be readily converted into sodium oxalate and this in turn into oxalic acid. Both the oxalic acid market and the formic acid market of the world were dominated by German manufacturers before the war; the new process may destroy this German advantage. The output of ammonia from the Bucher process may not, however, necessarily be limited by the market for formic and oxalic acids. By the action of air and steam at a low red heat, sodium cyanide yields ammonia and soda. Since the soda obtained may be used over and over again in the process itself with consequent reduction in cost of raw material, the development of the process, if financially successful, is limited only by the demand for ammonia. At present there is little prospect that ammonia can be made as the principal product by this method, but it may be produced as a by-product of the manufacture of formic and oxalic acids.

Bucher even dreams of revolutionizing the process of making steel, and obtaining sodium cyanide as a by-product of a new steel-making process. Pig iron, the primary product of the iron and steel industry, contains about 4 per cent of carbon. The process of making steel consists essentially in reducing the carbon content to a figure varying from about one-tenth of 1 per cent to 2 per cent, according to the variety of steel desired. In the Bessemer converter, the carbon is burned out by blowing a blast of air through the molten pig iron. Bucher hopes to replace this air blast by a blast of nitrogen carrying powdered soda and thereby to remove the carbon as sodium cyanide. Sodium cyanide thus produced would be so cheap that it might be converted by treatment with steam into ammonia for fertilizer, and soda for reuse in the steel-making operation. Since this process has not yet passed the laboratory stage, prediction of success would be rash. However, chemical sci-

ence has to its credit scores of triumphs inherently no more difficult or improbable than this. There is at least a hope that, within the next decade or two, the steel industry may yield large amounts of nitrogen fertilizer material as a by-product.

*Summary of the Situation at the Outbreak of the War*

At the outbreak of the war the situation in regard to the development of the four processes outlined was briefly as follows:

The arc process had been successfully developed in Norway on a considerable scale in three large plants and there were smaller plants located in France, Italy, and Austria. The combined production may be estimated at about 19,000 tons of fixed nitrogen per year. The growth of the industry had been limited by the scarcity of power available at a price low enough to be attractive to this process. Altho some experimental work had been done in the United States on a fairly large scale, there was no plant in successful commercial operation.

The cyanamid process had developed on a scale perhaps three times as large as the arc process with an actual output of about 31,000 short tons of fixed nitrogen. (See page 410.) As this method is not so dependent on cheap power the plants were more widely distributed, being located in Norway, Sweden, Switzerland, Germany, Italy, France, Canada, Japan, and Austria. There was no plant in the United States but a large plant at Niagara Falls, Canada, had been erected with capital and personnel derived from the United States, and a large part of the product was sold in the United States.

The Haber process was in operation in a single plant in Germany and many of the technical details were not

known to outsiders. The output from this process in Germany prior to the war (1913) has been reported as about 7000 tons of nitrogen or about one-third of that of the arc process.

The Bucher process was only in the early laboratory experimental stages and no serious attempts had yet been made to develop it on a large scale.

The following table shows the world's resources in fixed nitrogen compounds during 1913, the figures all being expressed in terms of short tons of fixed nitrogen to make them comparable (in part they represent productive capacity at close of 1913 instead of actual production).

NITROGEN INDUSTRIES COMPARED IN 1913<sup>1</sup>

Product or process	Production or estimated productive capacity in terms of short tons of fixed nitrogen
Chilean nitrate . . . . .	429,897
By-product ammonia . . . . .	319,667
Calcium cyanamid . . . . .	66,138
Arc process . . . . .	18,739
Haber process . . . . .	6,614
Total . . . . .	841,055

#### IV. DEVELOPMENTS IN NITROGEN FIXATION SINCE THE OUTBREAK OF THE EUROPEAN WAR

##### *Norway, Sweden, and Switzerland*

Among the neutral nations Norway held the leading position before the war in the fixation of atmospheric nitrogen. Plants operating both the arc process and the cyanamid process were in operation in Norway during 1913, the product being sold in the form of nitrate of lime, calcium cyanamid, and ammonium nitrate. The ammonium nitrate is made from cyanamid-ammonia

<sup>1</sup> From Final Report of Nitrogen Products Committee, Ministry of Munitions of War, Great Britain.

and nitric acid (made by the arc process). The development during the war is shown by the following table:

STATISTICS OF NORWEGIAN NITROGEN INDUSTRY <sup>1</sup>

(Short tons)

Product exported	1913	1914	1915	1916	1917
Ammonium nitrate . . . . .	10,039	13,182	29,166	65,740	70,082
Nitrate of lime . . . . .	78,183	82,866	42,559	50,707	39,596
Calcium cyanamid . . . . .	24,373	15,124	27,126	14,497	2,550
Total export expressed as nitrogen <sup>2</sup> . . . . .	18,065	18,109	20,624	32,210	33,993

The rapid growth, shown in the table above, in the production of ammonium nitrate accompanied by a drop in the other products reflects the military demand for ammonium nitrate. When computed in terms of fixed nitrogen, in 1913 about 18,000 short tons of nitrogen were fixed and by 1917 the amount had increased to about 34,000 short tons of nitrogen in Norway. The production of cyanamid in Sweden, which was 613 short tons <sup>3</sup> in 1911, reached 20,229 short tons in 1913 and in 1917 was more than 110,000 tons according to the best available estimates. In Switzerland the output of cyanamid was 8,267 short tons in 1913 and rose to 44,092 short tons during 1918.

### *Germany and Austria*

Germany during the war relied on the development of the Haber and cyanamid processes to supply her with

<sup>1</sup> Published in Final Report of Nitrogen Products Committee, Ministry of Munitions of War.

<sup>2</sup> Calculated on basis of 35 per cent of nitrogen in ammonium nitrate, 13 per cent in nitrate of lime, and 18 per cent in calcium cyanamid.

<sup>3</sup> This figure and most of the others quoted on this and the following pages are taken from the Report of the Nitrogen Products Committee, Ministry of Munitions of War (British).

the necessary requirements of fixed nitrogen. The output in Germany by the Haber process increased from about 7,000 short tons in 1913 to about 215,000 short tons in 1918. The output by the cyanamid process increased from 4,760 short tons of fixed nitrogen in 1913 to 60,000 tons in 1918. It has been estimated that when finally completed the annual output of fixed nitrogen by plants under construction during the war and using synthetic processes (Haber and cyanamid) will be about 419,000 short tons of nitrogen. This figure is about three times the nitrogen content of the Chilean nitrate annually imported by Germany before the war. This great increase in the output of synthetic nitrogen in Germany was not accompanied by any substantial increase in the output of by-product ammonia from the coking of coal. In 1913 the output of by-product ammonia in Germany was equivalent to about 121,253 short tons of nitrogen. The output at the conclusion of the war is placed at not over 134,000 short tons.

A considerable fraction of the ammonia made by these processes was oxidized to nitric acid, which served as the indispensable raw material for the manufacture of explosives. Germany was cut off from imports of Chilean nitrate at the very beginning of the war, but is known to have captured a large supply estimated at 400,000 tons in Antwerp (equivalent to 62,000 tons fixed nitrogen). This large capture together with the existing stocks and plants kept the German explosive plants in operation until the new large nitrogen fixation plants referred to above were built. The Germans were able to build these extensions in time because successful plants were already in operation and every technical detail was known to them. New plants, therefore, could be erected at once, without delay for experimentation, and with assurance that when completed they would work satisfactorily.

In actual completed productive capacity and in detailed technical knowledge of how to design and operate plants according to the Haber process, Germany undoubtedly leads the world today.

Austria made an increase in her output of cyanamid but not sufficient to compensate for decreased imports from Chile. Her total output, as compared with the German output, was insignificant. Austria, Bulgaria, and Turkey evidently relied on Germany for their supplies of explosives.

### *Japan, Italy, France, and Great Britain*

In the Allied countries there was not the same necessity as in Germany to erect nitrogen fixation plants, because supplies could be secured from Chile directly, or indirectly in the form of explosives made in America. Altho the first cyanamid plant was erected on Italian soil, the industry has developed comparatively slowly there. The output in Italy in 1913 was 16,515 short tons, rose to 27,673 tons in 1916 but fell to 16,535 tons in 1918.<sup>1</sup> Additional plants under construction are expected to bring the Italian production up to 88,000 tons per year. The production of cyanamid <sup>1</sup> in Japan rose from 7,716 short tons in 1913 to 55,000 tons in 1918. In addition Japan made a big gain in her output of ammonium sulphate <sup>1</sup> from coke ovens, 100,799 short tons in 1918 as compared with only 8,800 in 1913.

France suffered a decrease in output of by-product ammonia due to German invasion of much of her coal-producing territories. France had a cyanamid plant in successful operation at the outbreak of the war with an output of about 8,000 tons. By 1918 the French output had increased to 110,000 tons with additional plants

<sup>1</sup> Figures published by International Institute of Agriculture, Rome, Italy.

under construction sufficient to make a productive capacity of more than 300,000 tons.

The British supremacy of the sea made it unnecessary for Great Britain to undertake immediately a great building program for fixed nitrogen plants on a par with the German program. To be sure there was a serious danger to England in the submarine menace, but if the submarines succeeded in making a blockade of England effective, England was lost regardless of the supplies of nitrate. A policy of depending primarily on imports was therefore sound. England could and did take the time to investigate thoroly and to plan for the reconstruction period as well as for the war period.

A large technical committee known as the Nitrogen Products Committee, which was appointed by the Ministry of Munitions of War, undertook a comprehensive investigation of the whole subject from the economic, military, scientific, and technical standpoints. An Interim Report from this committee was submitted to the Minister of Munitions on February 22, 1917. A "Final Report" of this committee was made public in February, 1920, altho printed for confidential official distribution under date of May 10, 1919. This report is unquestionably the most thoro and reliable discussion of the economic and military aspects of the subject which has yet been published. Furthermore, much scientific and technical work was carried out under the direction of this committee, but the results of these experiments have not yet been made known in detail. The committee reached the conclusion<sup>1</sup> that both cyanamid and Haber plants could be operated with commercial success under the conditions likely to prevail in England after the war, and recommended in its

<sup>1</sup> See par. 638 of the Final Report referred to above.



Interim Report <sup>1</sup> the erection of both in England in accordance with detailed plans which it prepared. The Minister accepted the recommendation as to the erection of the Haber plant and the construction had been begun at the time of the signing of the Armistice, but had progressed little beyond the laying of foundations. It has since been transferred to the Brunner-Mond Company — the largest English chemical firm — and will be put into operation. The recommendation to erect a cyanamid plant was not accepted by the Minister because the construction of the large power plant needed would require from eighteen months to two years. The recommendation relating to the erection of a large cyanamid plant was, however, repeated by the Committee after the signing of the Armistice under date of May 10, 1919. So far as the writer is aware no action has been taken.

### *United States*

The first attempt to operate the arc process on a commercial scale had been made at Niagara Falls in 1901, but proved a commercial failure on account of unsuitable design of the furnaces and was soon abandoned. This early American enterprise, however, aided the later development of the industry in Norway by showing clearly the nature of the technical difficulties to be overcome. Subsequently the process was introduced in North Carolina on European models but was soon abandoned, because it proved to be more profitable to sell the power for other purposes. A small plant using " off-peak " power has lately been put into operation near Tacoma, Washington.

At the beginning of the war the Bucher process was in its early experimental stages only.

<sup>1</sup> See par. 656 and pp. 140-142 of the Final Report referred to above.

In 1914 the cyanamid process was not actually in operation in the United States, but the plant of the American Cyanamid Company, one of the largest in the world, was located at Niagara Falls, Canada. Its personnel and capital were American, and its product was sold mainly in the United States.

The increased demand for nitrogen due to the outbreak of the war resulted in an increased output of the cyanamid in the Niagara Falls plant and also of coke-oven ammonia. Furthermore it stimulated experimental study of the subject. The General Chemical Company undertook extensive investigations of the synthetic ammonia process. The Bucher process emerged from the laboratory of Brown University and the large-scale experimental work needed for its development was undertaken by the Nitrogen Products Company, a corporation organized for the purpose. The Air Reduction Company also entered the field beginning the development of a process whose nature has been carefully guarded, but which is believed to be similar to the Bucher process in the basic chemical principles, altho considerably different in engineering design.

It was not until June 3, 1916 that any steps were taken by the government of the United States to encourage nitrogen fixation. The National Defense Act of 1916 made an appropriation of \$20,000,000 to be expended by the President for the fixation of nitrogen for military and fertilizer purposes. A committee composed of leading American chemists and engineers was appointed to advise the President as to the best method of accomplishing this result. Dr. Charles L. Parsons of the Bureau of Mines, was sent to Europe by the War Department to study the subject. The cooperation of all American firms interested in the problem was secured. As a result of the report of this first

committee and of the report made by Dr. Parsons a new committee was appointed to consider and harmonize the two reports. This committee reached the conclusion that the Haber process is the one best suited to the industrial and economic conditions existing in the United States. At that time the Haber patents were still in effect in the United States. The General Chemical Company, which had been for some years investigating the synthesis of ammonia, believed that they had succeeded in developing a process which did not infringe on the Haber patents, but which was an improvement on the process. These conclusions were based on laboratory and semi-works experiments rather than on the successful operation of units of commercial size. The General Chemical Company offered to make the results of its investigations available to the government on generous terms and to cooperate in every way in the erection of a plant. The government was given detailed plans and specifications and the services of many technical experts without any charge, provided the product was used only by the government for military purposes; but a royalty of \$5.00 per ton was to be paid on any fixed nitrogen sold commercially for fertilizer. The nitrate committee recommended that \$4,000,000 out of the Congressional appropriation of \$20,000,000 be used for the erection of a plant in accordance with the plans of the General Chemical Company. The plans also provided for the conversion of a part of the ammonia produced into nitric acid which was to be combined with the remaining ammonia to make the explosive ammonium nitrate. This recommendation was accepted by the War Department and on Oct. 15, 1917 the erection of Nitrate Plant No. 1 was begun near Sheffield, Alabama. This plant was planned to have a capacity of about 10,000 tons of ammonia equivalent to 8,500 tons of fixed nitrogen per year.

The Committee also recommended that steps should be taken to develop the Bucher process. The Nitrogen Products Company had been experimenting on a large scale with the Bucher process and offered to put its entire experience at the disposal of the government on the same terms as those offered by the General Chemical Company. The committee, however, reached the conclusion that tho the Bucher process is fundamentally sound, further experiments on details of design would be advisable before the erection of a large commercial factory would be justified. They therefore recommended that \$200,000 should be made available for further experiments on this process under the direction of the War Department.

The entry of the United States into the war radically changed the situation. The demands for explosives were enormously increased, and the alarming success of the German submarines during 1917 made dependence on Chile for nitrates increasingly dangerous. The possibility had to be faced that the German submarines would secure virtual command of the sea. In such a contingency England must inevitably acknowledge defeat. But the United States, altho denied a definite victory, could at least avoid defeat through invasion as long as the supply of explosives did not cease for lack of nitrates. With an adequate supply of nitrates available from the air, the United States and Canada together could defend themselves against invasion indefinitely even if completely shut off from imports by sea. No other imported article is really essential for the national existence and defense.

It was, therefore, sound public policy to take steps to ensure an adequate supply of nitrates from sources beyond the reach of the submarine. The nitrate program of the War Department was enormously increased.

Certainty of production at an early date became the paramount consideration, and comparative cost and probable competitive strength after the war were of minor importance.

The cyanamid process was in successful large scale operation at Niagara Falls, Canada, and the technical knowledge of the staff of this plant was available to the government of the United States. A cyanamid plant could consequently be erected with assurance that when completed it would function properly without long delays to correct mistakes in design almost inevitable when the design is based solely on small scale experiments.

Altho no large scale plant for the conversion of ammonia into nitric acid was in operation in the United States, much experimental work on the process had been carried out by the American Cyanamid Company, and by the Bureau of Mines in coöperation with the Semet-Solvay Company. These experiments had been sufficiently successful to justify reliance on this method in connection with the Haber and cyanamid processes in preference to the arc process, which was excluded on account of its enormous power requirements. Accordingly Nitrate Plant No. 2 was started near the Muscle Shoals on the Tennessee River near Sheffield, Alabama. It was designed to produce 220,000 tons of calcium cyanamid equivalent to 41,500 tons of fixed nitrogen annually. It is expected ultimately to use water power from Muscle Shoals, but since at least three years will be required to build the dams and power houses a steam power plant was erected to furnish the power needed at once.

Before the construction of Plant No. 2 had proceeded very far, the program was again increased and orders given for the construction of Plant No. 3 near Toledo and Plant No. 4 near Cincinnati.

Furthermore, at the direct request of the French government, a plant to produce ten tons of sodium cyanide per day by the Bucher process was erected at Saltville, Virginia, by the Bureau of Mines, acting as the agent of the War Department. The French government desired to use this material for the manufacture of poison gases.

At the date of the signing of the Armistice, Plants No. 1 and 2 were in operation in part, altho all the units were not yet completed, and the cyanide plant at Saltville, Virginia, was also in operation. Plants No. 3 and 4 had advanced only a little beyond the preliminary work of clearing the land and laying foundations. Further work on No. 3 and No. 4 was stopped, and these plants have been abandoned.

Plant No. 1, which was to produce synthetic ammonia, however, was not completely successful. Mistakes were made in the design so that the completed plant did not operate in an entirely satisfactory way. This is not surprising since the designs were based on experiments on a much smaller size, and no one in America had any experience in the operation of a large size commercial plant. Ordinary business prudence, which requires that every detail of design should be perfected through construction, operation, and modification of a single large size unit before the construction of a large plant of many units, was deliberately neglected in this case on account of the urgent necessity for speed. Much of the construction is of good usable quality, including railroad connections, the village for workmen, power plant, repair shops, offices, factory buildings, and a large part of the special manufacturing equipment. Some of the special equipment for the process will have to be redesigned and rebuilt. The titles to the patents on the Haber process have been seized by the Alien

Property Custodian and, therefore, the need of avoiding infringement will no longer hamper the reconstruction of the plant. There can be little doubt that it can be put in good working condition by the expenditure of a small fraction of the original cost. The cyanamid plant (Nitrate Plant No. 2) is of good design and in good working order, the design having been prepared by engineers experienced in the operation of a successful large plant.

The cyanide plant at Saltville, Virginia, was ready for operation a few days before the signing of the Armistice and some units were put into operation and yielded cyanide. But, as a result of the cessation of war needs, no attempt was made to secure capacity output, and after a short trial operation the plant was shut down. Altho it was undoubtedly an important advance in the art of making cyanides, further improvements in design, especially in the furnaces, may be necessary before the process will prove commercially successful in normal times.

## V. THE FUTURE POLICY OF THE UNITED STATES

All the nitrogen fixation plants were closed down soon after the Armistice, because the appropriations under which they were built provided that they were intended to produce war materials, and the War Department did not feel authorized under the law to operate them for the manufacture of fertilizer for sale to the public. The War Department has, however, organized a large research laboratory, under the direction of Professor Lamb of Harvard, for the purpose of studying and experimenting on the technical problems involved in the design and operation of these plants in the expectation that Congress will authorize their permanent operation for supplying fertilizer in peace and munitions in war.

The large capital investment has now been lying idle for more than a year. No fertilizer has been produced. Before production can begin it is necessary for Congress to determine a permanent policy and to pass the necessary legislation. There are several alternatives. (a) The plants might be operated by the government for the production and sale of fertilizer in times of peace; being then available for munitions if ever again needed. (b) They might be sold to private corporations under such conditions as would ensure operation. (c) The operation of the plants might be abandoned and the plants dismantled either directly by the government or by sale for the price of junk to private concerns, who would dismantle them or convert them into other uses.

Whatever is done with them the government must assume a considerable loss on the cost of the plants. They were built during the period of the war under a cost plus contract, and with every emphasis on speed rather than economy. There was much extra cost through payments for overtime labor and through premiums for prompt delivery of materials. A considerable fraction of expense must therefore be charged off as a part of the cost of the war, and the plants written down at least to the cost of reproducing them at the present time with all engineering mistakes eliminated. The cyanide plant at Saltville has already been offered for sale by the War Department.

Senator Wadsworth has introduced a bill (S. 3390), which provides for the operation of these plants by a quasi-public corporation to be known as the United States Fixed Nitrogen Corporation. The government is to turn over Nitrate Plants No. 1 and No. 2 and the Muscle Shoals Power Plant, now under construction, and to supply a working capital of \$12,500,000 (or so much thereof as may be needed), and in return receive



the entire capital stock of the corporation. The directors of the corporation are to be appointed by the Secretary of War, who shall be ex-officio Chairman of the Board of Directors. The plan would place the corporation under ordinary commercial law and free it from the usual government red tape in managing its finances and personnel. It is understood to have the support of the Army and the Navy Departments. No action has yet been taken (May 1, 1920) by Congress, but a committee of the Senate has been holding public hearings on the bill referred to above. During these hearings Secretary of War Baker, General Williams, Chief of Ordnance, and other officers of the War Department urged government operations of the plants in accordance with the plan of the Wadsworth bill. It was pointed out that the operation of these plants would reduce the need for a reserve supply of nitrate such as is now held by the War Department for emergencies, and that the working capital required could be secured by the sale of one half of this emergency supply; hence no additional appropriation from the Treasury would be required to put the plan into effect. On the other hand, F. S. Washburn, President of the American Cyanamid Company argued against the operation of these plants by the government. The Committee on Expenditures in the War Department of the House of Representatives has also taken much testimony dealing with the construction and future disposition of these plants.

A discussion of the pros and cons of private and government operation of manufacturing enterprises is beyond the scope of this article. The important question is whether the plants are to be operated or dismantled. To allow them to stand idle is nearly equivalent to dismantling them, because they would rapidly deteriorate. Without an experienced operating staff and the constant

improvements which come with operating experience they would be of little use in an emergency. If they can earn interest on any figure above their sale price as junk, it will be profitable for the government from a purely financial point of view to have them operated. Moreover, if operated, they will be an important military asset and, if the need ever arises, will ensure that the United States can make itself independent of imports of nitrate from Chile, just as Germany did. Should this need never arise, these plants will continue to furnish a large supply of nitrogenous fertilizers, and thus increase the food supply. There can be no danger of excessive supplies of fertilizer material. There is plenty of land to put it on which has never received a pound of commercial fertilizer. In some way, and soon, the existing legal obstacles to the operation of the plants should be removed, in order that they may forthwith contribute to the production of food for a starving world.

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