

Detonator of the population explosion

Without ammonia, there would be no inorganic fertilizers, and nearly half the world would go hungry. Of all the century's technological marvels, the Haber–Bosch process has made the most difference to our survival.

Vaclav Smil

What is the most important invention of the twentieth century? Aeroplanes, nuclear energy, space flight, television and computers will be the most common answers. Yet none of these can match the synthesis of ammonia from its elements. The world might be better off without Microsoft and CNN, and neither nuclear reactors nor space shuttles are critical to human well-being. But the world's population could not have grown from 1.6 billion in 1900 to today's six billion without the Haber–Bosch process.

Every one of us has to eat ten essential amino acids to synthesize the body proteins needed for tissue growth and maintenance. Agricultural crops and animals fed on crops supply almost nine-tenths of these amino acids in food proteins (aquatic species and animals grazing on grassland provide the rest). The yield of intensive agriculture is almost always limited by the availability of the nitrogen needed to produce these proteins.

Nitrogen comes from biofixation (by *Rhizobium* bacteria symbiotic with legumes and by cyanobacteria), from atmospheric deposition, and from the recycling of crop residues and animal manures. But these sources only add up to about half the global need: the other half must come from inorganic nitrogen fertilizers, whose synthesis was made possible by Fritz Haber's invention and Carl Bosch's ingenuity.

The synthesis of ammonia belongs to that special group of discoveries — including Edison's light bulb and the Wright brothers' flight — for which we can pinpoint the date of the decisive breakthrough. The archives of Badische Anilin- und Soda-Fabrik (BASF) in Ludwigshafen, Germany, contain a letter that Haber, a professor of physical chemistry and electrochemistry at the Technische Hochschule in Karlsruhe, sent on 3 July 1909 to the company's directors.

In it, Haber describes the events of the previous day, when two BASF chemists came to his laboratory to see the synthesis demonstrated: "Yesterday we began operating the large ammonia apparatus with gas circulation in the presence of Dr [Alwin] Mittasch, and were able to run it for about five hours without interruption. During this whole time it functioned correctly and produced liquid ammonia continuously ... All parts of the apparatus were tight and functioned well, so it was easy to conclude that the experiment could be repeated."

Twenty years later, Robert Le Rossignol,

Haber's English assistant, remembered that both Bosch and Mittasch came to witness the morning experiment. Paul Krassa, another of Haber's students, recalled the tension that tends to accompany such momentous events, and the fear of *Tücke des Objekts* (the spite of things). Indeed, one of the bolts of the high-pressure apparatus sprang during the tightening, delaying the demonstration for several hours; Bosch could not stay in the afternoon and returned to Ludwigshafen.

But BASF's leaders were reluctant to proceed with the development of a synthesis running at pressures above 10 MPa (100 atm). August Bernthsen, head of BASF's laboratories, was horrified: "One hundred atmospheres! Just yesterday we had an autoclave under a mere seven atmospheres flying into the air!" But Bosch, who ran the company's nitrogen-fixation research, was confident: "I believe it can go. I know exactly the capability

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of the steel industry. It should be risked." And he did it: he solved some unprecedented engineering problems, and commercial production of ammonia began on 9 September 1913, just four years and two months after Haber's laboratory demonstration.

Today's ammonia synthesis has been improved in many details and is much more energy-efficient, but Haber and Bosch would recognize all the main features of their invention. Global output of ammonia is now about 130 million tonnes a year; four-fifths of this goes into fertilizers, of which urea is the most important. Rich countries could fertilize much less by cutting their excessive food production and by eating fewer animals — but even the most assiduous recycling of organic wastes and the widest planting of legumes could not supply enough nitrogen for land-scarce, poor and populous nations.

For several decades, virtually all the fixed nitrogen added to the fields of China, Egypt and Indonesia has come from synthetic fertilizers. When you travel in Hunan or Jiangsu, through the Nile Delta or the manicured landscapes of Java, remember that the children running around or leading docile water buffalo got their body proteins, via the urea their parents spread on the fields, from the Haber–Bosch synthesis of ammonia. Without this, almost two-fifths of the world's population would not be here — and our dependence will only increase as the global count moves from six to nine or ten billion people. □

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Haber (right) invented the process while Bosch brought the necessary engineering skills.