ISSN 2624-9081 • DOI 10.26034/roadsides-202501310

Ammonia Synthesis:

Entering a Ubiquitous Chemical Technosphere

Benjamin Steininger

The molecule ammonia (NH3) is synthesized under high pressure and with the help of catalysts from atmospheric nitrogen (N2) and from hydrogen (H), which is gained either from water or more commonly from natural gas. The geographer Vaclav Smil (2001) ranked this chemical process—pioneered by Fritz Haber and Carl Bosch in the early years of the last century—above iconic innovations of modernity such as computers, television and space travel. As a core compound of industrial fertilizers, ammonia was central to the 'green revolution' in agriculture and thus to global food production. As a key compound of ammunition, ammonia has also been involved in mass destruction. Finally, as a technological platform, the process of ammonia synthesis gave rise to petrochemistry. In these three ways, this process contributes behind the scenes ('infra') to the fundamental conditions of most of the visible structures integral to the twentieth century and the Anthropocene.

Certain aspects of this story are well known. In Germany, the Haber–Bosch process is one of the landmarks of scientific success. Since 1913 ammonia was produced at Oppau-Ludwigshafen by BASF—just in time to supply ammunition for the First World War. The reputation of Fritz Haber encapsulates the tensions inherent in this: he has been both ostracized as a war criminal for inventing poison gas as a weapon and awarded with a Nobel Prize in 1918 for inventing ammonia synthesis (Szöllösi-Janze 1998). Other aspects of this industry remain invisible. Few would have heard of companies like CF-Industries, Yara, Nutrien, OCI, Qatar Fertilizer Company, Sinofert, Safco—world market leaders in producing substances that end up becoming part of our very own bodies.

This article rethinks the industrial infrastructures of ammonia synthesis and follows some of its associated toxicities. Particular attention is paid to the openness of these infrastructures. High-pressure ammonia plant facilities work as clearly defined environments. But the reactors and tubular structures of an ammonia plant only form the visible core of a technical structure which puts into communication almost all planetary spheres—resources from the atmosphere and lithosphere, with processes in the biosphere and hydrosphere—plus a wide set of economies, politics and further technologies.

Microlandscape on the Haber–Bosch catalyst surface, a high-pressure reactor, World War I battlefield, algal bloom in Baltic Sea, war news on an ammonia pipeline in Ukraine.
Collage: Author, 2024.

Questions of scale are central to the industry of ammonia synthesis. Catalysis chemists themselves describe their understanding of the process as “multiscalar” (Schlögl 2015: 3535). What they deal with stretches over fifteen orders of magnitude between the picoseconds and nanometers of actual molecular interactions, microseconds of “surface transport” on the catalyst materials to the meter and hour ranges of the visible industrial machinery (Ibid.).

Yet where the scales of ammonia production end, the ranges of impact that define its role only begin—in agricultures, economies, histories, ecologies and, as Anthropocene scholarship shows, in actual and future Earth systems—adding further orders of magnitude to the picture. Cultural theory and geography are challenged to interpret those multiscalar processes of ammonia synthesis and their products as a central part of the global “technosphere” (Haff 2014: 126) that defines the actual and future human condition. For such an endeavor it is not just the quantitative scales that matter, but even more so the qualitative implications of technological interventions that practically and theoretically blur formerly defined frontiers between natural and cultural or historical processes.

Ammonia synthesis is on many levels an almost classic example of techno-science. Even the catalyst that is used to connect nitrogen and hydrogen is not a natural material but was invented around 1910 by BASF (Ertl 2008): it is a solid body composed of iron with chemical additives of potash, calcium, aluminum and oxygen. On an engineering level, the process necessitates high-pressure apparatuses to meet the thermodynamic needs of the reaction: around 200–300 bar pressure and 400–500 degrees Celsius. It also involves production units before and after to create the synthesis gas (a mix of hydrogen and nitrogen), as well as to further process ammonia into marketable products such as fertilizers. Shortly after experimental proofs in 1909, production plants opened in 1913 (Oppau-Ludwigshafen) and 1917 (Merseburg-Leuna). After the First World War, the Allies also started to use the process. Even today, however, it takes the full mobilization of all ranges of physico-chemical infrastructures such as femtosecond lasers (fmsec = 0,000.000.000.000.001 sec), photoemission electron microscopy and digital modelling to—still not fully—grasp what happens during the process on and within the catalyst's surfaces (Ertl 2008; Ertl and Soentgen 2015).

The interpretation of this infrastructure, and its respective forms of toxicity, means interpreting interactions of the technology with very different environments—including biological-material spheres but also spheres of socio-cultural institutions and politics, which enable and maintain this type of techno-science. In this sense, ammonia synthesis belongs both to micro-chemistry and to macro-politics.

With the fixation of nitrogen the vast space of the atmosphere has become a chemical resource of planetary technology. In quantitative terms, the industrial process fixes as much nitrogen as all the natural processes of nitrogen fixation on Earth, such as in bacteria through the help of enzymes like nitrogenase. With the second chemical resource, hydrogen, the precise sites of production plants are also connected to vast areas and economies of extraction, such as the natural gas fields in the lithosphere. A full flowchart of the process before and after the plant could start literally anywhere in the atmosphere and end anywhere in the biosphere, seeing as over the last century large parts of both were affected by intentional fertilizer use and even more by its unintended consequences.

This contrasts the concept of control as a core issue of the whole project of ammonia synthesis—on a molecular level as a high-pressure technology, and as a means to technologically correct the unavoidable loss of fixed nitrogen from soils—identified in the nineteenth century as a distortion of formerly closed nitrogen cycles between plant and animal organisms. The project of planetary correction, the establishment of a controlled 'second nature,' was a failure, giving way to landscapes that can be defined as "third nature" (Böhme 2018), as hybrids of technological planning and unavoidably uncontrollable dynamics. Soils and landscapes affected by ammonia synthesis are paradigmatic third natures. Less than a third of the fertilizer applied to agricultural land reaches the actual arable crop and, thus, food production (Ertl and Soentgen

2015: 14). The rest is washed away, leading to large-scale water problems due to algal blooms. The drastic effects of fertilizers therefore involve both the planned growth of arable crops for world markets and unplanned oceanic dead zones, prominently in the Gulf of Mexico and the Baltic Sea.

This is most salient form of toxicity of ammonia synthesis infrastructures. Yet obviously, toxicity here is not to be considered as an absolute mechanism. It is the specific interactions between chemical products, agricultural systems and aquatic life—and thus a whole set of relationships between different process regimes and infrastructures—that produce the concrete effect. Not only is it infrastructures that need to be scrutinized for their toxicity, but also toxicities should be examined for their infrastructural aspects (Murphy 2017).

What type of toxicity should be addressed at a particular site and in a specific historical scenario depends very much on the location in question. It also depends on epistemological interest. A scholarly perspective on the political and historical environments of this industry can identify forms of toxicity (e.g. connections to war crimes and injustice) that could go unnoticed by chemical toxicologists.

Two types of sites offer good examples with respect to their geographical-historical--political-ecological networks of toxicity. The first type is represented by Oppau-Ludwigshafen and Leuna in Germany, which were the first industrial ammonia plants on the planet. Their most obvious form of toxicity lies in the field of war technology. The violence of the battlefields at Verdun was somehow anticipated in the high-pressure reactors of the hinterland. In the famous explosion of the fertilizer silo in Oppau in 1920—almost an anticipation of the explosion in the port of Beirut in 2020—this destructive power was tangible in peacetime without being debated in terms of ecological explosiveness or toxicity. Following its gaining of "technological momentum" (Hughes 1969), however, from the 1920s onwards ammonia synthesis became central to the development of other high-pressure technologies, in particular in petrochemistry. The political environment of this technological breakthrough involved US partners from the oil industry, such as Standard Oil of New Jersey. It also led to close ties between I.G. Farben (into which BASF was merged in 1926) and the German Nazi regime. I.G. Farben even managed parts of the Auschwitz concentration camp complex and was heavily involved in the Shoah.

Also sites of postwar ammonia production are embedded both in biological and political environments. Whereas the principle of catalytic high-pressure synthesis was retained and simply optimized, the source of hydrogen changed to natural gas. New ecological toxicity is consequently involved on the input side, since natural gas is a highly problematic resource due to methane leakage and extraction by way of shale fracking with its notoriously toxic additives. The world's biggest ammonia factories were built near large natural gas fields from the 1960s onwards in Louisiana, at the "sacrifice zone"—the petrochemical corridor on former plantations that carries not just ecological also but historical-political burdens of enslavement (Lerner 2012; Misrach and Orff 2012; Bullard 2015). In the 1970s, the USSR's biggest plants were constructed on the Volga as part of a large USA–USSR ammonia versus grain deal (Gerlach 2010: 485), involving an ammonia pipeline from Togliatti to Odessa which was in operation until 2023. Under the conditions of globalization since 1990, large plants were built in China and on the Persian Gulf. Ammonia and thus food production appears more than ever intimately connected to all the manifold ecological and geopolitical pitfalls of petromodernity.

Future fertilizer infrastructures might work with different catalysts, reduced energy consumption or green hydrogen, and may entail less run-off. Nonetheless, as long as the nitrate industry unavoidably connects lithospheric, biospheric, atmospheric and technospheric processes, the need to reflect on its specific planetary ambivalences, contradictions and toxicities will stay.

References:

Böhme, Hartmut. 2018. “Ökologie, Ästhetik und Technik in der dritten Natur.” In *Dritte Natur. Technik. Kapital. Umwelt,* edited by Steffen Richter and Andreas Rötzer, 7–22. Berlin: Matthes & Seitz Berlin.

Bullard, Robert D. 2015. “Environmental justice in the 21st century: Race still matters.” *Phylon* 52: 72–94.

Ertl, Gerhard. 2008. “Reactions at surfaces: From atoms to complexity” (Nobel lecture). *Angewandte Chemie International Edition* 47 (19): 3524–35.

Ertl, Gerhard and Jens Soentgen (eds). 2015. *N. Stickstoff—ein Element schreibt Weltgeschichte.* Munich: oekom.

Gerlach, Christian. 2010. “Das US-amerikanisch-sowjetische Getreidegeschäft 1972.” In *Ökonomie im Kalten Krieg. Studien zum Kalten Krieg* (Band 4), edited by Bernd Greiner, Christian Müller and Claudia Weber, 480–500. Hamburg: Hamburger Edition.

Haff, Peter. 2014. “Humans and Technology in the Anthropocene: Six Rules.” *The Anthropocene Review* 1 (2): 126–36.

Hughes, Thomas. 1969. “Technological momentum in history: Hydrogenation in Germany 1898–1933.” *Past & Present* 44: 106–32.

Lerner, Steve. 2012. *Sacrifice Zones: The Front Lines of Toxic Chemical Exposure in the United States.* Boston: MIT Press.

Misrach, Richard and Kate Orff. 2012. *Petrochemical America.* New York: Aperture.

Murphy, Michelle. 2017. “Alterlife and Decolonial Chemical Relations.” *Cultural Anthropology* 32 (4): 494-503.

Schlögl, Robert. 2015. “Heterogene Katalysatoren – fundamental betrachtet.” *Angewandte Chemie* 127 (11): 3531–89.

Smil, Vaclav. 2001. *Enriching the Earth: Fritz Haber, Carl Bosch, and the Transformation of World Food Production.* Cambridge, MA: MIT Press.

Szöllösi-Janze, Margit. 1998. *Fritz Haber.* 1868–1934. *Eine Biographie.* München: Beck.

Cite as:

Steininger, Benjamin. 2025. "Ammonia Synthesis: Entering a Ubiquitous Chemical Technosphere." *Roadsides* 13: 69–74. https://doi.org/10.26034/roadsides-202501310

Author:

Benjamin Steininger is a historian of science and technology, a cultural and media theorist and a curator. He is affiliated as Postdoc Researcher to the Cluster of Excellence "Unifying Systems in Catalysis" at Technical University Berlin and to the Max Planck Institute of Geoanthropology at Jena. His research focuses on the role of industrial catalysis in modernity and Anthropocene and on petromodernity. Together with Alexander Klose, in 2016 he founded the research collective Beauty of Oil. In 2021, Benjamin and Alexander curated "Oil. Beauty and Horror in the Petrol Age," the first retrospective on the arts in petromodernity at Kunstmuseum Wolfsburg, Germany. In 2024, they published the book Atlas of Petromodernity (Santa Barbara: punctumbooks).

Roadsides is a diamond Open Access journal designated to be a forum devoted to exploring the social, cultural and political life of infrastructure.

roadsides.net
editor@roadsides.net
@road_sides
@roadsides_journal

Collection no. 013 was edited by: Nikolaos Olma and Janine Hauer
Editors-in-chief: Agnieszka Joniak-Lüthi and Tina Harris
Managing editors: Matthäus Rest
Copyediting: David Hawkins
Layout: Antoni Kwiatkowski and Chantal Hinni

ISSN 2624-9081