INDUSTRIES OF INDIA · INDUSTRY STUDIES

# Synthetic Nitrogen Fertilizer

*The Source Companion*

Ketineni Ramarao

INDUSTRIES OF INDIA

# Method and Honest Limits

This companion mirrors the chapters of *Synthetic Nitrogen Fertilizer: Air, Fire, Bread*. In the book itself, every section that rests on outside sources ends with a small superscript source mark - for example [S6, S27] - printed at the end of the section's last paragraph. Each mark resolves here in one step: find the source number in the matching chapter's section below, and you have what the source is, the specific claims this book took from it, its URL, and how fully it was read. The marks were assigned section by section from the author's own research notes - each tag names the sources whose recorded facts actually appear in that section - and the assignment was verified programmatically: for every tagged section, the distinctive figures in the section text were checked against the tagged sources' research notes, and every section whose figures did not check out against its tags was re-mapped before publication. A second pass then checked the prose's distinctive named claims - people, places, plants, processes - against the full text of the tagged sources; where texture rested on material beyond the original fifty sources, eleven supplementary sources (S51 - S61, listed at the end of this companion) were located, read and added, and the affected sections' tags extended. Where a section makes a synthetic or argumentative point rather than citing figures, its tag names the sources behind the facts it discusses.

**Read status is stated honestly.** "Read in full" means the whole page or document was read. "Search excerpt / highlights only" means the source was consulted through search-result excerpts, not read end to end; claims resting only on such sources are correspondingly thinner, and the book leans on them for corroboration, not for load-bearing figures. A handful of company figures are as-published by the company and carry the company's own rounding; they are not independently audited here. Wikipedia entries were used as tertiary guides to the technical and historical record, and where a Wikipedia figure matters to the argument it is corroborated by a primary source elsewhere in the same chapter's list.

**Forecasts, targets and scenarios** - the IEA's 2050 scenario quantities, DNV's 2030 shipping projections, the AEA's project pipeline counts, company production guidance - are estimates about the future, quoted as the source stated them; they are labeled as estimates in the book's text wherever they drive a claim.

**Known unit caveat:** industry statistics variously count tonnes of ammonia, tonnes of contained nitrogen, and tonnes of nutrient; the book states the unit where it matters, and the figures below carry the source's own basis.

COMPANION

# The Item (Introduction)

S4 · OWID/Ritchie 2017

~half of global population fed by synthetic N fertilizer; Erisman et al. 2008 (Nature Geoscience): supported 42% of global births over past century; 44% of population 2000; 48% 2008; Rosa & Gabrielli 2023 ~half in 2019; Smil 2004: harvests ~half without N fertilizer; 85% of food protein N from cropland; N fertilizer ~40% of dietary protein mid-1990s; Stewart 2005: 30-50% of yield increase attributable to fertilizer (362 seasons). https://ourworldindata.org/how-many-people-does-synthetic-fertilizer-feed

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S5 · Erisman et al. 2008 Nature Geoscience "How a century of ammonia synthesis changed the world"

https://www.nature.com/articles/ngeo325

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S6 · IEA Ammonia Technology Roadmap exec summary

~70% of ammonia used for fertilizers; ammonia = 2% (8.6 EJ) of total final energy; 40% of energy input as feedstock; >70% of production via gas SMR; 170 bcm natural gas (20% of industrial gas demand); 75 Mtce coal (5% industrial coal); direct emissions 450 Mt CO2; indirect ~170 Mt CO2; ~2.4 t CO2/t (2x steel, 4x cement, direct basis); China 30% of production & 45% of CO2; US/EU/India/Russia/ME 8-10% each; ammonia exports ~10% of production; urea trade ~30% of production; avg energy intensity 41 GJ/t net; BAT 28 GJ/t gas, 36 GJ/t coal; plants up to 50-yr lifetimes; avg age 25y (Europe 40, China 12); near-zero projects ~8 Mt by 2030 (3% of 2020 capacity); near-zero routes 10-100% cost premium; SDS: 110 GW electrolyser + 90 Mt CO2 transport/storage by 2050; SDS investment $14bn/yr. https://www.iea.org/reports/ammonia-technology-roadmap/executive-summary

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S37 · Smil SciAm 1997

traditional recycling+legumes max ~200 kg N/ha/yr theoretical -> 200-250 kg plant protein -> theoretical 15 people/ha; practical ~5 people/ha (China 5-6, NW Europe ~5); ammonia <5 Mt until late 1940s; 1950s to 10 Mt; 1960s innovations cut electricity use >90%. https://vaclavsmil.com/wp-content/uploads/2024/10/Smil_SciAm_N2cycle.pdf

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*Read status: Read in full.*

S49 · IEA note

~170 Mt ammonia/yr (Nature Synthesis focus: "around 170 million metric tonnes of ammonia are produced globally"). https://www.nature.com/articles/s44160-023-00362-y

https://www.nature.com/articles/s44160-023-00362-y

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# Chapter One - The Quiet Ceiling

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https://www.nature.com/articles/ngeo325

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S26 · Wikipedia History of the Haber process

Liebig 1840s; Chincha Islands 1820s-1860s, 12.5 Mt guano exhausted; Saltpeter War 1879, Chile victory 1881; Chile 1900: 2/3 of world fertilizer; Germany imports 350 kt (1900) -> 900 kt (1912); Crookes 1898 warning; Hildebrandt 1795 attempts; Ostwald 1900 attempt, Bosch asked to validate; Le Chatelier 1901 ammonia synthesis, explosion killed assistant, stopped; Frank-Caro industrialized 1905, by 1918 35 sites 325 kt N/yr; Birkeland-Eyde 1905, Norsk Hydro founded 2 Dec 1905; 1911 50,000 kW, 1912 100,000 kW; 1913 12,000 t N (~5% of coke-oven volume); Haber 1905 Thermodynamik book; Nernst rivalry 1907; March 1909 lab demo; osmium & uranium catalysts early 1909; July 1909: 250 mL ammonia per 2 hours; Bosch "I think it can work... We should risk it."; Mittasch ~20,000 catalysts tested by 1920, iron-based found Sept 1909 line; hydrogen embrittlement; double-wall reactor solution; Krupp built reactors 2.44 m high; Oppau construction began May 7 1911; production from 9 Sept 1913; 30 t/day 1913; 8,700 t ammonia 1914 -> 36,000 t ammonium sulfate; WWI nitric acid for explosives under blockade; Leuna. https://en.wikipedia.org/wiki/History_of_the_Haber_process

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S38 · Smil 2002 Ambio (Royal Swedish Academy)

protein/diet nitrogen balance details. http://www.ask-force.org/web/Developing/Smil-Nitrogen-Food-Production-2002.pdf

http://www.ask-force.org/web/Developing/Smil-Nitrogen-Food-Production-2002.pdf

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# Chapter Two - Bird Islands and Desert Salt

S26 · Wikipedia History of the Haber process

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S36 · Wisniak & Garces rise/fall of salitre

1900 Chile provided two-thirds of fertilizer nitrogen used worldwide. http://desarrollocurricular.uantof.cl/wp-content/uploads/2024/01/The-rise-and-fall-of-the-salitre-sodium-nitrate-industry-Wisniak-y-Garces.pdf

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S48 · AHR guano

1840s-1930s Peru/Chile exported hundreds of millions of tons guano + sodium nitrate. https://doi.org/10.1093/ahr/117.4.1028

https://doi.org/10.1093/ahr/117.4.1028

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# Chapter Three - Fire in the Arc

S2 · Yara breakthrough page

Feb 1903 Sam Eyde met Kristian Birkeland at dinner hosted by minister Gunnar Knudsen; Eyde wanted hydropower fertilizer; Birkeland had high-voltage arc technique. https://www.yara.com/knowledge-grows/the-breakthrough-that-helped-feed-the-world/

https://www.yara.com/knowledge-grows/the-breakthrough-that-helped-feed-the-world/

*Read status: Read in full.*

S3 · Hydro history

Norsk Hydro established 1905; power from Europe's largest hydropower plant (Telemark). https://www.hydro.com/en/global/about-hydro/company-history-content/history-in-brief/

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S26 · Wikipedia History of the Haber process

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# Chapter Four - Lime That Breathes Nitrogen

S26 · Wikipedia History of the Haber process

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S28 · Wikipedia Frank-Caro

CaC2 + N2 -> CaCN2 + C at ~1,000C; developed 1895-1899; first factories 1905 Piano d'Orta (Italy), Westeregeln (Germany); Odda Norway 1908, 12,000 t/yr from 1909, largest; peak 1945 ~1.5 Mt/yr calcium cyanamide. https://en.wikipedia.org/wiki/Frank-Caro_process

https://en.wikipedia.org/wiki/Frank-Caro_process

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S29 · ACS landmark calcium carbide

Moissan 1893 observed carbide absorbs N2; Rothe 1898 identified calcium cyanamide; Frank & Caro patent.
https://www.acs.org/education/whatischemistry/landmarks/calciumcarbideacetylene.html

https://www.acs.org/education/whatischemistry/landmarks/calciumcarbideacetylene.html

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# Chapter Five - Bread from Air

S1 · BASF chronology 1913 page

BASF team under Carl Bosch working since 1908 on Haber's Karlsruhe lab procedure; first ammonia synthesis plant at Oppau 1913. https://www.basf.com/global/en/who-we-are/history/chronology/1902-1924/1913

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S26 · Wikipedia History of the Haber process

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S32 · Wikipedia Fritz Haber

1909 first synthetic ammonia (500C, 2900 psi, catalyst, lab scale); Nobel 1918; Manifesto of the Ninety-Three Oct 1914; head of Chemistry Section Ministry of War; chlorine at Second Battle of Ypres Apr-May 1915, present personally; team 150 scientists

1,300 technical staff; Clara Immerwahr first woman PhD chemistry Breslau, m. 1901, d. 1915; Haber died 1934. https://en.wikipedia.org/wiki/Fritz_Haber

https://en.wikipedia.org/wiki/Fritz_Haber

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S33 · Nobel Prize org

Chemistry 1918 Fritz Haber (1/1); Bosch 1931. https://www.nobelprize.org/prizes/chemistry/1918/summary/

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S50 · Leuna works wiki

Leuna subsidiary of IG Farben, one of world's largest chemical plants; ammonia intermediate for nitric acid for fertilizer and explosives; WWI demand exceeded Oppau; first ammonia tankers April 1917. https://en.wikipedia.org/wiki/Leuna_works ; https://tu-freiberg.de/en/ig-farben/poster7

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# Chapter Six - The Chemistry of Pressure

S6 · IEA Ammonia Technology Roadmap exec summary

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S45 · C&EN 1963

"600 T/D ammonia plant biggest in U.S.A. engineering and construction by M.W. Kellogg" Feb 1963. https://doi.org/10.1021/cen-v041n008.p067

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S50 · Leuna works wiki

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# Chapter Seven - From Ammonia to the Field

S30 · Wikipedia Urea

Wöhler 1828 synthesized urea from inorganic (silver cyanate + ammonium chloride), vitalism blow; >90% of urea for fertilizer; 46% N highest of solid N fertilizers; biuret main impurity; Bosch-Meiser process patented 1922 (2 NH3 + CO2 -> carbamate -> urea + water, ~190C, 1.4-1.75 MPa); world capacity ~180 Mt 2020; UAN solution 32% N, 80% of US liquid fertilizers; prills vs granules. https://en.wikipedia.org/wiki/Urea

https://en.wikipedia.org/wiki/Urea

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S31 · Wikipedia Ostwald process

ammonia -> nitric acid, Pt-Rh gauze ~900C; 4NH3+5O2->4NO+6H2O; main route to nitrate fertilizers. https://en.wikipedia.org/wiki/Ostwald_process

https://en.wikipedia.org/wiki/Ostwald_process

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S40 · Montana State briefing

urea from liquid ammonia + CO2 Bosch-Meiser; integration with ammonia plants. https://www.ampc.montana.edu/documents/briefings/briefing112.pdf

https://www.ampc.montana.edu/documents/briefings/briefing112.pdf

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S41 · Ullmann/UreaKnowHow

urea from NH3+CO2 both from ammonia synthesis; exclusively this route today. https://ureaknowhow.com/wp-content/uploads/attachments/Urea%20different%20technologies.pdf

https://ureaknowhow.com/wp-content/uploads/attachments/Urea%20different%20technologies.pdf

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S43 · fert.nic.in (Govt of India Dept of Fertilizers)

urea MRP statutorily fixed at Rs 268/50 kg bag (incl. Rs 354/MT dealer margin); New Urea Policy 2015; neem-coated urea. https://www.fert.nic.in/urea_policy_administration

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# Chapter Eight - The Map of Production

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https://www.iea.org/reports/ammonia-technology-roadmap/executive-summary

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S7 · USGS MCS 2025 Nitrogen

US 2024: 18 companies, 37 plants, 17 states; ~55% US capacity in LA/OK/TX; plants ~80% of rated capacity; 88% of US ammonia to fertilizer; US production 14.0 Mt N 2024 (13.8 2023); world total ~150 Mt N 2024e (152 in 2023); China 47, India 15, Russia 14, US 14, Saudi 5.4, Egypt 5.0, Iran 4.2, Canada 3.6, Qatar 3.1, T&T 3.2 (Mt N 2024e); Gulf Coast ammonia avg price $440/short ton 2024 ($470 2023, $1,070 2022, $578 2021, $213 2020); Henry Hub avg ~$2.10/MMBtu 2024; US corn 37.0 M ha 2024 (-3%); world ammonia capacity +7% over next 4 years. https://pubs.usgs.gov/periodicals/mcs2025/mcs2025-nitrogen.pdf

https://pubs.usgs.gov/periodicals/mcs2025/mcs2025-nitrogen.pdf

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S8 · IFA Medium-Term Outlook 2025-2029 (June 2025)

2024 ammonia output 190.5 Mt (+3% y/y); urea 201 Mt (+3%); MOP 76.6 Mt record (+10%); phosphoric acid 89.6 Mt record; Europe N production rebounded 20% in 2024 (Germany, Netherlands, Hungary); Russia ammonia exports 82% below 2021 levels; demand growth led by China, Russia, Iran, Nigeria capacity. https://fertilizer.org/wp-content/uploads/2025/07/2025_IFA_Medium_Term_Outlook_Report.pdf

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S9 · IFA Short-Term Outlook 2024-2025

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S10 · CF Industries FY2024 PR

net earnings $1.22bn; adj EBITDA $2.28bn; net sales $5.94bn ($6.63bn 2023); gross ammonia production 9.8 Mt (9.5 in 2023); expects ~10 Mt 2025; avg gas cost $2.40/MMBtu 2024 vs $3.67 2023; China urea exports <300 kt 2024, -94% y/y; ~25% of European ammonia capacity in shutdown/curtailment Jan 2025; Brazil urea imports 8.3 Mt 2024 (+14%); Russia urea exports +16% through Q3 2024; US corn plantings ~93 M acres expected 2025. https://ir.cfindustries.com/Investors/news/news-details/2025/CF-Industries-Holdings-Inc.-Reports-Full-Year-2024-Net-Earnings-of-1.22-Billion-Adjusted-EBITDA-of-2.28-Billion/default.aspx

https://ir.cfindustries.com/Investors/news/news-details/2025/CF-Industries-Holdings-Inc.-Reports-Full-Year-2024-Net-Earnings-of-1.22-Billion-Adjusted-EBITDA-of-2.28-Billion/default.aspx

*Read status: Read in full.*

S15 · QAFCO

3.8 Mt ammonia + 5.6 Mt urea per year; world's largest single-site producer of ammonia & urea; 4 granular urea plants 12,900 MTPD; golden jubilee (founded 1969). https://www.qafco.qa/en/our-plants/

https://www.qafco.qa/en/our-plants/

*Read status: Read in full.*

S16 · EuroChem Northwest 1

largest single-train ammonia capacity in Europe, 1 Mt/yr; $1bn invested; KBR Purifier process; ~25% output to third parties; 300 permanent jobs; Northwest 2: 1.4 Mt urea + 1 Mt ammonia, first product expected start 2026. https://www.eurochemgroup.com/project/eurochem-northwest/

https://www.eurochemgroup.com/project/eurochem-northwest/

*Read status: Read in full.*

S17 · Nutrien FY2024

adjusted EBITDA $5.4bn total; Nitrogen adjusted EBITDA $1.9bn; net earnings $700m; nitrogen sales guidance 10.7-11.2 Mt 2025. https://www.nutrien.com/news/press-releases/nutrien-reports-fourth-quarter-and-full-year-2024-results-1717

https://www.nutrien.com/news/press-releases/nutrien-reports-fourth-quarter-and-full-year-2024-results-1717

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S18 · Yara Q4-2025 (Quartr summary of earnings)

FY2025 revenue $15,715M (2024: $13,934M); EBITDA ex special items $2,803M (+37%). https://quartr.com/events/yara-international-yar-q4-2025_3PQLySNS

https://quartr.com/events/yara-international-yar-q4-2025_3PQLySNS

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S42 · Mordor Intelligence

nitrogenous fertilizer market $104.18bn 2025 -> $107.78bn 2026 -> $127.82bn 2031, CAGR 3.46%; urea 44.1% share 2025; conventional 61.8% share; soil application 68.4%. https://www.mordorintelligence.com/industry-reports/nitrogenous-fertilizer-market

https://www.mordorintelligence.com/industry-reports/nitrogenous-fertilizer-market

*Read status: Read in full.*

S49 · IEA note

~170 Mt ammonia/yr (Nature Synthesis focus: "around 170 million metric tonnes of ammonia are produced globally"). https://www.nature.com/articles/s44160-023-00362-y

https://www.nature.com/articles/s44160-023-00362-y

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COMPANION

# Chapter Nine - Feeding Half the World

S4 · OWID/Ritchie 2017

~half of global population fed by synthetic N fertilizer; Erisman et al. 2008 (Nature Geoscience): supported 42% of global births over past century; 44% of population 2000; 48% 2008; Rosa & Gabrielli 2023 ~half in 2019; Smil 2004: harvests ~half without N fertilizer; 85% of food protein N from cropland; N fertilizer ~40% of dietary protein mid-1990s; Stewart 2005: 30-50% of yield increase attributable to fertilizer (362 seasons). https://ourworldindata.org/how-many-people-does-synthetic-fertilizer-feed

https://ourworldindata.org/how-many-people-does-synthetic-fertilizer-feed

*Read status: Read in full.*

S5 · Erisman et al. 2008 Nature Geoscience "How a century of ammonia synthesis changed the world"

https://www.nature.com/articles/ngeo325

https://www.nature.com/articles/ngeo325

*Read status: Read in full.*

S37 · Smil SciAm 1997

traditional recycling+legumes max ~200 kg N/ha/yr theoretical -> 200-250 kg plant protein -> theoretical 15 people/ha; practical ~5 people/ha (China 5-6, NW Europe ~5); ammonia <5 Mt until late 1940s; 1950s to 10 Mt; 1960s innovations cut electricity use >90%. https://vaclavsmil.com/wp-content/uploads/2024/10/Smil_SciAm_N2cycle.pdf

https://vaclavsmil.com/wp-content/uploads/2024/10/Smil_SciAm_N2cycle.pdf

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S39 · USDA ARS Green Revolution timeline

Norin No.10 from Japan 1946 via S. Cecil Salmon; Vogel Pullman; Gaines; Borlaug CIMMYT; 1963 India visit; tall native wheats lodged under heavy N; India wheat 12 Mt 1965 -> >20 Mt 1970 -> >37 Mt "last year"; Borlaug Nobel. https://www.ars.usda.gov/oc/timeline/green/

https://www.ars.usda.gov/oc/timeline/green/

*Read status: Read in full.*

COMPANION

# Chapter Ten - Beyond the Field

S6 · IEA Ammonia Technology Roadmap exec summary

~70% of ammonia used for fertilizers; ammonia = 2% (8.6 EJ) of total final energy; 40% of energy input as feedstock; >70% of production via gas SMR; 170 bcm natural gas (20% of industrial gas demand); 75 Mtce coal (5% industrial coal); direct emissions 450 Mt CO2; indirect ~170 Mt CO2; ~2.4 t CO2/t (2x steel, 4x cement, direct basis); China 30% of production & 45% of CO2; US/EU/India/Russia/ME 8-10% each; ammonia exports ~10% of production; urea trade ~30% of production; avg energy intensity 41 GJ/t net; BAT 28 GJ/t gas, 36 GJ/t coal; plants up to 50-yr lifetimes; avg age 25y (Europe 40, China 12); near-zero projects ~8 Mt by 2030 (3% of 2020 capacity); near-zero routes 10-100% cost premium; SDS: 110 GW electrolyser + 90 Mt CO2 transport/storage by 2050; SDS investment $14bn/yr. https://www.iea.org/reports/ammonia-technology-roadmap/executive-summary

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*Read status: Read in full.*

S23 · PMC Beirut review

Aug 4 2020, ~2,750 t ammonium nitrate, Hangar 12, stored since 2013; 220 dead, >6,500 injured, ~300,000 homeless; crater 140 m; magnitude 3.3; heard in Cyprus 125 mi; 9 hospitals damaged; ~30 AN events since 1916; AN decomposes >190-210C. https://pmc.ncbi.nlm.nih.gov/articles/PMC8212863/

https://pmc.ncbi.nlm.nih.gov/articles/PMC8212863/

*Read status: Read in full.*

S27 · Wikipedia Haber process

N2+3H2<->2NH3, dH=-92.28 kJ/mol; ~15% per pass, 97% overall with recycle; 150-250 bar (some 60-180 bar loops), 400-500C catalyst; iron from magnetite with K2O/Al2O3/CaO promoters; 2018 ~230 Mt ammonia; 1-2% of world energy; 72% via SMR (2012); China 75% coal/20% gas (2022); Kellogg single-train early 1960s; modern single-line >3,000 t/day; Ru catalysts in KBR KAAP since 1992; Hosono C12A7 electride 2012; SMR CH4+H2O->CO+3H2 (+206 kJ/mol). https://en.wikipedia.org/wiki/Haber_process

https://en.wikipedia.org/wiki/Haber_process

*Read status: Read in full.*

S30 · Wikipedia Urea

Wöhler 1828 synthesized urea from inorganic (silver cyanate + ammonium chloride), vitalism blow; >90% of urea for fertilizer; 46% N highest of solid N fertilizers; biuret main impurity; Bosch-Meiser process patented 1922 (2 NH3 + CO2 -> carbamate -> urea + water, ~190C, 1.4-1.75 MPa); world capacity ~180 Mt 2020; UAN solution 32% N, 80% of US liquid fertilizers; prills vs granules. https://en.wikipedia.org/wiki/Urea

https://en.wikipedia.org/wiki/Urea

*Read status: Read in full.*

S31 · Wikipedia Ostwald process

ammonia -> nitric acid, Pt-Rh gauze ~900C; 4NH3+5O2->4NO+6H2O; main route to nitrate fertilizers. https://en.wikipedia.org/wiki/Ostwald_process

https://en.wikipedia.org/wiki/Ostwald_process

*Read status: Read in full.*

S50 · Leuna works wiki

Leuna subsidiary of IG Farben, one of world's largest chemical plants; ammonia intermediate for nitric acid for fertilizer and explosives; WWI demand exceeded Oppau; first ammonia tankers April 1917. https://en.wikipedia.org/wiki/Leuna_works ; https://tu-freiberg.de/en/ig-farben/poster7

https://en.wikipedia.org/wiki/Leuna_works

https://tu-freiberg.de/en/ig-farben/poster7

*Read status: Read in full.*

COMPANION

# Chapter Eleven - The Gas Umbilical

S6 · IEA Ammonia Technology Roadmap exec summary

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https://www.iea.org/reports/ammonia-technology-roadmap/executive-summary

*Read status: Read in full.*

S7 · USGS MCS 2025 Nitrogen

US 2024: 18 companies, 37 plants, 17 states; ~55% US capacity in LA/OK/TX; plants ~80% of rated capacity; 88% of US ammonia to fertilizer; US production 14.0 Mt N 2024 (13.8 2023); world total ~150 Mt N 2024e (152 in 2023); China 47, India 15, Russia 14, US 14, Saudi 5.4, Egypt 5.0, Iran 4.2, Canada 3.6, Qatar 3.1, T&T 3.2 (Mt N 2024e); Gulf Coast ammonia avg price $440/short ton 2024 ($470 2023, $1,070 2022, $578 2021, $213 2020); Henry Hub avg ~$2.10/MMBtu 2024; US corn 37.0 M ha 2024 (-3%); world ammonia capacity +7% over next 4 years. https://pubs.usgs.gov/periodicals/mcs2025/mcs2025-nitrogen.pdf

https://pubs.usgs.gov/periodicals/mcs2025/mcs2025-nitrogen.pdf

*Read status: Read in full.*

S8 · IFA Medium-Term Outlook 2025-2029 (June 2025)

2024 ammonia output 190.5 Mt (+3% y/y); urea 201 Mt (+3%); MOP 76.6 Mt record (+10%); phosphoric acid 89.6 Mt record; Europe N production rebounded 20% in 2024 (Germany, Netherlands, Hungary); Russia ammonia exports 82% below 2021 levels; demand growth led by China, Russia, Iran, Nigeria capacity. https://fertilizer.org/wp-content/uploads/2025/07/2025_IFA_Medium_Term_Outlook_Report.pdf

https://fertilizer.org/wp-content/uploads/2025/07/2025_IFA_Medium_Term_Outlook_Report.pdf

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S10 · CF Industries FY2024 PR

net earnings $1.22bn; adj EBITDA $2.28bn; net sales $5.94bn ($6.63bn 2023); gross ammonia production 9.8 Mt (9.5 in 2023); expects ~10 Mt 2025; avg gas cost $2.40/MMBtu 2024 vs $3.67 2023; China urea exports <300 kt 2024, -94% y/y; ~25% of

European ammonia capacity in shutdown/curtailment Jan 2025; Brazil urea imports 8.3 Mt 2024 (+14%); Russia urea exports +16% through Q3 2024; US corn plantings ~93 M acres expected 2025. https://ir.cfindustries.com/Investors/news/news-details/2025/CF-Industries-Holdings-Inc.-Reports-Full-Year-2024-Net-Earnings-of-1.22-Billion-Adjusted-EBITDA-of-2.28-Billion/default.aspx

https://ir.cfindustries.com/Investors/news/news-details/2025/CF-Industries-Holdings-Inc.-Reports-Full-Year-2024-Net-Earnings-of-1.22-Billion-Adjusted-EBITDA-of-2.28-Billion/default.aspx

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S34 · Reuters Aug 2022

Yara cutting European ammonia to ~35% capacity use (-3.1 Mt ammonia, -4 Mt finished products annualized); BASF cuts Ludwigshafen/Antwerp; CF Fertilisers UK halted Billingham ammonia; Grupa Azoty Pulawy ~10% ammonia; PKN Orlen Anwil halted. https://www.reuters.com/markets/commodities/fertiliser-makers-cut-output-surging-gas-prices-2022-08-25/

https://www.reuters.com/markets/commodities/fertiliser-makers-cut-output-surging-gas-prices-2022-08-25/

*Read status: Read in full.*

S35 · Europarl written question Nov 2022

"Half of European ammonia production plant closed" (claim in question title). https://www.europarl.europa.eu/doceo/document/E-9-2022-003632_EN.html

https://www.europarl.europa.eu/doceo/document/E-9-2022-003632_EN.html

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S43 · fert.nic.in (Govt of India Dept of Fertilizers)

urea MRP statutorily fixed at Rs 268/50 kg bag (incl. Rs 354/MT dealer margin); New Urea Policy 2015; neem-coated urea. https://www.fert.nic.in/urea_policy_administration

https://www.fert.nic.in/urea_policy_administration

*Read status: Read in full.*

COMPANION

# Chapter Twelve - The Other Half

S6 · IEA Ammonia Technology Roadmap exec summary

~70% of ammonia used for fertilizers; ammonia = 2% (8.6 EJ) of total final energy; 40% of energy input as feedstock; >70% of production via gas SMR; 170 bcm natural gas (20% of industrial gas demand); 75 Mtce coal (5% industrial coal); direct emissions 450 Mt CO2; indirect ~170 Mt CO2; ~2.4 t CO2/t (2x steel, 4x cement, direct basis); China 30% of production & 45% of CO2; US/EU/India/Russia/ME 8-10% each; ammonia exports ~10% of production; urea trade ~30% of production; avg energy intensity 41 GJ/t net; BAT 28 GJ/t gas, 36 GJ/t coal; plants up to 50-yr lifetimes; avg age 25y (Europe 40, China 12); near-zero projects ~8 Mt by 2030 (3% of 2020 capacity); near-zero routes 10-100% cost premium; SDS: 110 GW electrolyser + 90 Mt CO2 transport/storage by 2050; SDS investment $14bn/yr. https://www.iea.org/reports/ammonia-technology-roadmap/executive-summary

https://www.iea.org/reports/ammonia-technology-roadmap/executive-summary

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S20 · Menaldo et al. 2022 Sci Rep

synthetic N fertilizer supply chain 1.13 GtCO2e in 2018 = 10.6% of agricultural emissions, 2.1% of global GHG; production 38.8%, field 58.6%, transport 2.6%; China+India+USA+EU28 = 62%. https://pmc.ncbi.nlm.nih.gov/articles/PMC9411506/

https://pmc.ncbi.nlm.nih.gov/articles/PMC9411506/

*Read status: Read in full.*

S21 · Richardson et al. 2023 Science Advances

N planetary boundary 62 Tg N/yr application; current industrial N fertilizer application 112 Tg N/yr; anthropogenic biological fixation 30-70 Tg; total intentional fixation 190 Tg N/yr; P boundary 11 Tg/yr (current 22 Tg/yr). https://www.science.org/doi/10.1126/sciadv.adh2458

https://www.science.org/doi/10.1126/sciadv.adh2458

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S22 · Eos 2021 (Lassaletta/AGU Advances study)

NUE declined 22% since 1961; half of N applied to crops lost; N2O ~300x more potent than CO2; Colombo Declaration goal to halve N waste by 2030. https://eos.org/articles/index-suggests-that-half-of-nitrogen-applied-to-crops-is-lost

https://eos.org/articles/index-suggests-that-half-of-nitrogen-applied-to-crops-is-lost

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S46 · Gulf of Mexico hypoxia literature

fertilizer-derived N runoff from Mississippi River Basin primary cause of Gulf hypoxic zone (Donner & Kucharik 2008 PNAS/ES&T; isotope evidence 2024 Comms Earth Env).

https://doi.org/10.1021/es070179e ; https://www.nature.com/articles/s43247-024-01873-y

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https://www.nature.com/articles/s43247-024-01873-y

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COMPANION

# Chapter Thirteen - When Fertilizer Becomes a Bomb

S23 · PMC Beirut review

Aug 4 2020, ~2,750 t ammonium nitrate, Hangar 12, stored since 2013; 220 dead, >6,500 injured, ~300,000 homeless; crater 140 m; magnitude 3.3; heard in Cyprus 125 mi; 9 hospitals damaged; ~30 AN events since 1916; AN decomposes >190-210C. https://pmc.ncbi.nlm.nih.gov/articles/PMC8212863/

https://pmc.ncbi.nlm.nih.gov/articles/PMC8212863/

*Read status: Read in full.*

S24 · BASF Oppau 1921 page

Sept 21 1921, 7:32 am; silo Op 110; ~4,500 t ammonium sulfate nitrate (50:50 AN/AS); blasting to loosen caked fertilizer (>20,000 prior blasts w/o incident); >500 dead, ~2,000 injured; crater 96 x 165 m, 18.5 m deep; windows burst 80 km away; seismographs in Munich 300 km. https://www.basf.com/global/en/who-we-are/history/Oppau1921

https://www.basf.com/global/en/who-we-are/history/Oppau1921

*Read status: Read in full.*

S25 · Wikipedia Texas City

Apr 16 1947; SS Grandcamp ~2,300 short tons AN; 581 dead; deadliest US industrial accident; AN made in Nebraska/Iowa, for export to postwar Europe. https://en.wikipedia.org/wiki/Texas_City_disaster

https://en.wikipedia.org/wiki/Texas_City_disaster

*Read status: Read in full.*

COMPANION

# Chapter Fourteen - The Next Molecule

S6 · IEA Ammonia Technology Roadmap exec summary

~70% of ammonia used for fertilizers; ammonia = 2% (8.6 EJ) of total final energy; 40% of energy input as feedstock; >70% of production via gas SMR; 170 bcm natural gas (20% of industrial gas demand); 75 Mtce coal (5% industrial coal); direct emissions 450 Mt CO2; indirect ~170 Mt CO2; ~2.4 t CO2/t (2x steel, 4x cement, direct basis); China 30% of production & 45% of CO2; US/EU/India/Russia/ME 8-10% each; ammonia exports ~10% of production; urea trade ~30% of production; avg energy intensity 41 GJ/t net; BAT 28 GJ/t gas, 36 GJ/t coal; plants up to 50-yr lifetimes; avg age 25y (Europe 40, China 12); near-zero projects ~8 Mt by 2030 (3% of 2020 capacity); near-zero routes 10-100% cost premium; SDS: 110 GW electrolyser + 90 Mt CO2 transport/storage by 2050; SDS investment $14bn/yr. https://www.iea.org/reports/ammonia-technology-roadmap/executive-summary

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*Read status: Read in full.*

S11 · CF/JERA/Mitsui Blue Point PR Apr 8 2025

JV for one of world's largest low-carbon ammonia facilities ~$4bn. https://www.cfindustries.com/newsroom/2025/blue-point-joint-venture ; Reuters: $4 billion low-carbon ammonia facility https://www.reuters.com/sustainability/climate-energy/cf-industries-forms-jv-4-billion-low-carbon-ammonia-facility-2025-04-08/

https://www.cfindustries.com/newsroom/2025/blue-point-joint-venture

https://www.reuters.com/sustainability/climate-energy/cf-industries-forms-jv-4-billion-low-carbon-ammonia-facility-2025-04-08/

*Read status: Read in full.*

S12 · AEA LEAD May 2025

516 projects (635 phases) = 457.7 Mt announced low-emission/transitional ammonia; Dec 2022: 103 projects; Blue Point Number One ATR FID April 2025: 1.4 Mt/yr ammonia, 2.3 Mt CO2 sequestered by 1PointFive, Technip EPC; ATOME Villeta Paraguay ~0.1 Mt electrolysis; Northern Lights FID expand 1.5->5 Mt CO2; Yara 0.8 Mt CO2/yr from Sluiskil from 2026; 46.6 Mt could be operational 2030 (4.1 operational, 14.0 firm, 28.6 mature); gas reformation 25.8 Mt of 2030; electrolysis reaches 17.9 Mt by 2030. https://ammoniaenergy.org/wp-content/uploads/2025/05/AEA-LEAD-Plants-Executive-Summary-May-2025.pdf

https://ammoniaenergy.org/wp-content/uploads/2025/05/AEA-LEAD-Plants-Executive-Summary-May-2025.pdf

*Read status: Read in full.*

S13 · AEA status article

Q3 (2025): operational renewable ammonia projects exceeded 1 GW installed electrolyser capacity first time; >85% alkaline. https://ammoniaenergy.org/articles/status-of-renewable-ammonia-projects-and-

technology-licensors/

https://ammoniaenergy.org/articles/status-of-renewable-ammonia-projects-and-technology-licensors/

*Read status: Read in full.*

S14 · DNV Sep 2025

"Ammonia in Shipping" report; 39 ammonia-fuelled vessels on order; blue+green ammonia production confirmed plans to 14 MTPA by 2030; bunkering trials Singapore, Rotterdam; two-phase pathway; IMO 2023 targets: -20% GHG vs 2008 by 2030, -70% by 2040, net zero 2050. https://www.dnv.com/news/2025/new-report-ammonia-shows-notable-progress-as-maritime-fuel-but-barriers-remain/

https://www.dnv.com/news/2025/new-report-ammonia-shows-notable-progress-as-maritime-fuel-but-barriers-remain/

*Read status: Read in full.*

S19 · Yara Herøya PR June 10 2024

24 MW renewable hydrogen plant, largest of its kind in Europe; electrolysis replaces gas feedstock; cuts 41,000 t CO2/yr; first low-carbon fertilizer tonnes delivered to Lantmännen; Yara Climate Choice portfolio; Northern Lights binding CO2 T&S agreement 2023 (world's first cross-border CCS agreement in operation), 800,000 t CO2/yr from Sluiskil; Yara emissions -45% since 2005. https://www.yara.com/corporate-releases/yara-opens-renewable-hydrogen-plant-a-major-milestone/

https://www.yara.com/corporate-releases/yara-opens-renewable-hydrogen-plant-a-major-milestone/

*Read status: Read in full.*

S44 · Pivot Bio

microbes convert atmospheric N at crop roots; PROVEN 40 replaces up to 40 lbs synthetic N/acre. https://www.pivotbio.com/our-technology

https://www.pivotbio.com/our-technology

*Read status: Site pages read; company-provided figures.*

COMPANION

# Chapter Fifteen - Closing the Loop

S22 · Eos 2021 (Lassaletta/AGU Advances study)

NUE declined 22% since 1961; half of N applied to crops lost; N2O ~300x more potent than CO2; Colombo Declaration goal to halve N waste by 2030. https://eos.org/articles/index-suggests-that-half-of-nitrogen-applied-to-crops-is-lost

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S27 · Wikipedia Haber process

N2+3H2<->2NH3, dH=-92.28 kJ/mol; ~15% per pass, 97% overall with recycle; 150-250 bar (some 60-180 bar loops), 400-500C catalyst; iron from magnetite with K2O/Al2O3/CaO promoters; 2018 ~230 Mt ammonia; 1-2% of world energy; 72% via SMR (2012); China 75% coal/20% gas (2022); Kellogg single-train early 1960s; modern single-line >3,000 t/day; Ru catalysts in KBR KAAP since 1992; Hosono C12A7 electride 2012; SMR CH4+H2O->CO+3H2 (+206 kJ/mol). https://en.wikipedia.org/wiki/Haber_process

https://en.wikipedia.org/wiki/Haber_process

*Read status: Read in full.*

S43 · fert.nic.in (Govt of India Dept of Fertilizers)

urea MRP statutorily fixed at Rs 268/50 kg bag (incl. Rs 354/MT dealer margin); New Urea Policy 2015; neem-coated urea. https://www.fert.nic.in/urea_policy_administration

https://www.fert.nic.in/urea_policy_administration

*Read status: Read in full.*

S44 · Pivot Bio

microbes convert atmospheric N at crop roots; PROVEN 40 replaces up to 40 lbs synthetic N/acre. https://www.pivotbio.com/our-technology

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S46 · Gulf of Mexico hypoxia literature

fertilizer-derived N runoff from Mississippi River Basin primary cause of Gulf hypoxic zone (Donner & Kucharik 2008 PNAS/ES&T; isotope evidence 2024 Comms Earth Env). https://doi.org/10.1021/es070179e ; https://www.nature.com/articles/s43247-024-01873-y

https://doi.org/10.1021/es070179e

https://www.nature.com/articles/s43247-024-01873-y

*Read status: Read in full.*

S47 · 4R stewardship

right source, right rate, right time, right place (UF/IFAS HS1264). https://ask.ifas.ufl.edu/publication/HS1264

https://ask.ifas.ufl.edu/publication/HS1264

*Read status: Read in full.*

COMPANION

# Chapter Sixteen - The Long Equilibrium

S6 · IEA Ammonia Technology Roadmap exec summary

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S8 · IFA Medium-Term Outlook 2025-2029 (June 2025)

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S12 · AEA LEAD May 2025

516 projects (635 phases) = 457.7 Mt announced low-emission/transitional ammonia; Dec 2022: 103 projects; Blue Point Number One ATR FID April 2025: 1.4 Mt/yr ammonia, 2.3 Mt CO2 sequestered by 1PointFive, Technip EPC; ATOME Villeta Paraguay ~0.1 Mt electrolysis; Northern Lights FID expand 1.5->5 Mt CO2; Yara 0.8 Mt CO2/yr from Sluiskil from 2026; 46.6 Mt could be operational 2030 (4.1 operational, 14.0 firm, 28.6 mature); gas reformation 25.8 Mt of 2030; electrolysis reaches 17.9 Mt by 2030. https://ammoniaenergy.org/wp-content/uploads/2025/05/AEA-LEAD-Plants-Executive-Summary-May-2025.pdf

https://ammoniaenergy.org/wp-content/uploads/2025/05/AEA-LEAD-Plants-Executive-Summary-May-2025.pdf

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S14 · DNV Sep 2025

"Ammonia in Shipping" report; 39 ammonia-fuelled vessels on order; blue+green ammonia production confirmed plans to 14 MTPA by 2030; bunkering trials Singapore, Rotterdam; two-phase pathway; IMO 2023 targets: -20% GHG vs 2008 by 2030, -70% by

2040, net zero 2050. https://www.dnv.com/news/2025/new-report-ammonia-shows-notable-progress-as-maritime-fuel-but-barriers-remain/

https://www.dnv.com/news/2025/new-report-ammonia-shows-notable-progress-as-maritime-fuel-but-barriers-remain/

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S42 · Mordor Intelligence

nitrogenous fertilizer market $104.18bn 2025 -> $107.78bn 2026 -> $127.82bn 2031, CAGR 3.46%; urea 44.1% share 2025; conventional 61.8% share; soil application 68.4%. https://www.mordorintelligence.com/industry-reports/nitrogenous-fertilizer-market

https://www.mordorintelligence.com/industry-reports/nitrogenous-fertilizer-market

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COMPANION

# Annexes

### S7 · USGS MCS 2025 Nitrogen

US 2024: 18 companies, 37 plants, 17 states; ~55% US capacity in LA/OK/TX; plants ~80% of rated capacity; 88% of US ammonia to fertilizer; US production 14.0 Mt N 2024 (13.8 2023); world total ~150 Mt N 2024e (152 in 2023); China 47, India 15, Russia 14, US 14, Saudi 5.4, Egypt 5.0, Iran 4.2, Canada 3.6, Qatar 3.1, T&T 3.2 (Mt N 2024e); Gulf Coast ammonia avg price $440/short ton 2024 ($470 2023, $1,070 2022, $578 2021, $213 2020); Henry Hub avg ~$2.10/MMBtu 2024; US corn 37.0 M ha 2024 (-3%); world ammonia capacity +7% over next 4 years. https://pubs.usgs.gov/periodicals/mcs2025/mcs2025-nitrogen.pdf

https://pubs.usgs.gov/periodicals/mcs2025/mcs2025-nitrogen.pdf

*Read status: Read in full.*

### S8 · IFA Medium-Term Outlook 2025-2029 (June 2025)

2024 ammonia output 190.5 Mt (+3% y/y); urea 201 Mt (+3%); MOP 76.6 Mt record (+10%); phosphoric acid 89.6 Mt record; Europe N production rebounded 20% in 2024 (Germany, Netherlands, Hungary); Russia ammonia exports 82% below 2021 levels; demand growth led by China, Russia, Iran, Nigeria capacity. https://fertilizer.org/wp-content/uploads/2025/07/2025_IFA_Medium_Term_Outlook_Report.pdf

https://fertilizer.org/wp-content/uploads/2025/07/2025_IFA_Medium_Term_Outlook_Report.pdf

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### S10 · CF Industries FY2024 PR

net earnings $1.22bn; adj EBITDA $2.28bn; net sales $5.94bn ($6.63bn 2023); gross ammonia production 9.8 Mt (9.5 in 2023); expects ~10 Mt 2025; avg gas cost $2.40/MMBtu 2024 vs $3.67 2023; China urea exports <300 kt 2024, -94% y/y; ~25% of European ammonia capacity in shutdown/curtailment Jan 2025; Brazil urea imports 8.3 Mt 2024 (+14%); Russia urea exports +16% through Q3 2024; US corn plantings ~93 M acres expected 2025. https://ir.cfindustries.com/Investors/news/news-details/2025/CF-Industries-Holdings-Inc.-Reports-Full-Year-2024-Net-Earnings-of-1.22-Billion-Adjusted-EBITDA-of-2.28-Billion/default.aspx

https://ir.cfindustries.com/Investors/news/news-details/2025/CF-Industries-Holdings-Inc.-Reports-Full-Year-2024-Net-Earnings-of-1.22-Billion-Adjusted-EBITDA-of-2.28-Billion/default.aspx

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### S15 · QAFCO

3.8 Mt ammonia + 5.6 Mt urea per year; world's largest single-site producer of ammonia & urea; 4 granular urea plants 12,900 MTPD; golden jubilee (founded 1969). https://www.qafco.qa/en/our-plants/

https://www.qafco.qa/en/our-plants/

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S16 · EuroChem Northwest 1

largest single-train ammonia capacity in Europe, 1 Mt/yr; $1bn invested; KBR Purifier process; ~25% output to third parties; 300 permanent jobs; Northwest 2: 1.4 Mt urea + 1 Mt ammonia, first product expected start 2026. https://www.eurochemgroup.com/project/eurochem-northwest/

https://www.eurochemgroup.com/project/eurochem-northwest/

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S19 · Yara Herøya PR June 10 2024

24 MW renewable hydrogen plant, largest of its kind in Europe; electrolysis replaces gas feedstock; cuts 41,000 t CO2/yr; first low-carbon fertilizer tonnes delivered to Lantmännen; Yara Climate Choice portfolio; Northern Lights binding CO2 T&S agreement 2023 (world's first cross-border CCS agreement in operation), 800,000 t CO2/yr from Sluiskil; Yara emissions -45% since 2005. https://www.yara.com/corporate-releases/yara-opens-renewable-hydrogen-plant-a-major-milestone/

https://www.yara.com/corporate-releases/yara-opens-renewable-hydrogen-plant-a-major-milestone/

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S21 · Richardson et al. 2023 Science Advances

N planetary boundary 62 Tg N/yr application; current industrial N fertilizer application 112 Tg N/yr; anthropogenic biological fixation 30-70 Tg; total intentional fixation 190 Tg N/yr; P boundary 11 Tg/yr (current 22 Tg/yr). https://www.science.org/doi/10.1126/sciadv.adh2458

https://www.science.org/doi/10.1126/sciadv.adh2458

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S23 · PMC Beirut review

Aug 4 2020, ~2,750 t ammonium nitrate, Hangar 12, stored since 2013; 220 dead, >6,500 injured, ~300,000 homeless; crater 140 m; magnitude 3.3; heard in Cyprus 125 mi; 9 hospitals damaged; ~30 AN events since 1916; AN decomposes >190-210C. https://pmc.ncbi.nlm.nih.gov/articles/PMC8212863/

https://pmc.ncbi.nlm.nih.gov/articles/PMC8212863/

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S24 · BASF Oppau 1921 page

Sept 21 1921, 7:32 am; silo Op 110; ~4,500 t ammonium sulfate nitrate (50:50 AN/AS); blasting to loosen caked fertilizer (>20,000 prior blasts w/o incident); >500 dead, ~2,000 injured; crater 96 x 165 m, 18.5 m deep; windows burst 80 km away; seismographs in Munich 300 km. https://www.basf.com/global/en/who-we-are/history/Oppau1921

https://www.basf.com/global/en/who-we-are/history/Oppau1921

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S26 · Wikipedia History of the Haber process

Liebig 1840s; Chincha Islands 1820s-1860s, 12.5 Mt guano exhausted; Saltpeter War 1879, Chile victory 1881; Chile 1900: 2/3 of world fertilizer; Germany imports 350 kt (1900) -> 900 kt (1912); Crookes 1898 warning; Hildebrandt 1795 attempts; Ostwald 1900 attempt, Bosch asked to validate; Le Chatelier 1901 ammonia synthesis, explosion killed assistant, stopped; Frank-Caro industrialized 1905, by 1918 35 sites 325 kt N/yr; Birkeland-Eyde 1905, Norsk Hydro founded 2 Dec 1905; 1911 50,000 kW, 1912 100,000 kW; 1913 12,000 t N (~5% of coke-oven volume); Haber 1905 Thermodynamik book; Nernst rivalry 1907; March 1909 lab demo; osmium & uranium catalysts early 1909; July 1909: 250 mL ammonia per 2 hours; Bosch "I think it can work... We should risk it."; Mittasch ~20,000 catalysts tested by 1920, iron-based found Sept 1909 line; hydrogen embrittlement; double-wall reactor solution; Krupp built reactors 2.44 m high; Oppau construction began May 7 1911; production from 9 Sept 1913; 30 t/day 1913; 8,700 t ammonia 1914 -> 36,000 t ammonium sulfate; WWI nitric acid for explosives under blockade; Leuna. https://en.wikipedia.org/wiki/History_of_the_Haber_process

https://en.wikipedia.org/wiki/History_of_the_Haber_process

*Read status: Read in full.*

S27 · Wikipedia Haber process

N2+3H2<->2NH3, dH=-92.28 kJ/mol; ~15% per pass, 97% overall with recycle; 150-250 bar (some 60-180 bar loops), 400-500C catalyst; iron from magnetite with K2O/Al2O3/CaO promoters; 2018 ~230 Mt ammonia; 1-2% of world energy; 72% via SMR (2012); China 75% coal/20% gas (2022); Kellogg single-train early 1960s; modern single-line >3,000 t/day; Ru catalysts in KBR KAAP since 1992; Hosono C12A7 electride 2012; SMR CH4+H2O->CO+3H2 (+206 kJ/mol).
https://en.wikipedia.org/wiki/Haber_process

https://en.wikipedia.org/wiki/Haber_process

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S43 · fert.nic.in (Govt of India Dept of Fertilizers)

urea MRP statutorily fixed at Rs 268/50 kg bag (incl. Rs 354/MT dealer margin); New Urea Policy 2015; neem-coated urea. https://www.fert.nic.in/urea_policy_administration

https://www.fert.nic.in/urea_policy_administration

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VERIFICATION

# Supplementary Sources S51 - S61

These eleven sources were added during the final verification pass. After the manuscript was tagged, every distinctive named claim in the prose - people, places, plants, processes - was checked against the full text of its tagged sources. Where the historical texture of a section rested on material not present in the original fifty, the supporting text was located, read, and added here, and the section's tag was extended. Read status below is exact.

### S51 Wikipedia Guano

Humboldt popularized guano in Europe; Chincha Islands deposits; coolie labor; Peruvian boom; War of the Pacific context.

https://en.wikipedia.org/wiki/Guano

*Read status: Read in full (verification pass).*

### S52 Wikipedia Chincha Islands

guano extraction history, labor conditions, Peruvian export economy.

https://en.wikipedia.org/wiki/Chincha_Islands

*Read status: Read in full (verification pass).*

### S53 Wikipedia Point Lisas

Point Lisas industrial estate, Trinidad and Tobago, ammonia/methanol complex.

https://en.wikipedia.org/wiki/Point_Lisas

*Read status: Read in full (verification pass).*

### S54 Wikipedia Night soil

night soil collection and use in China and Japan as fertilizer.

https://en.wikipedia.org/wiki/Night_soil

*Read status: Read in full (verification pass).*

### S55 Wikipedia Muscle Shoals, Alabama

WWI nitrate plants at Muscle Shoals; Tennessee Valley; fertilizer/munitions programs.

https://en.wikipedia.org/wiki/Muscle_Shoals,_Alabama

*Read status: Read in full (verification pass).*

### S56 Wikipedia Vemork

Vemork hydroelectric plant at Rjukan, Norsk Hydro, Telemark.

https://en.wikipedia.org/wiki/Vemork

*Read status: Read in full (verification pass).*

### S57 Wikipedia Svelgfoss

Svelgfoss power station near Notodden, Norsk Hydro arc-process era.

https://en.wikipedia.org/wiki/Svelgfoss

*Read status: Read in full (verification pass).*

S58 Wikipedia Billingham Manufacturing Plant

ICI Billingham, ammonia and fertiliser production from the 1920s.

https://en.wikipedia.org/wiki/Billingham_Manufacturing_Plant

*Read status: Read in full (verification pass).*

S59 Wikipedia Norfolk four-course system

Norfolk rotation, clover and turnips, British agricultural revolution.

https://en.wikipedia.org/wiki/Norfolk_four-course_system

*Read status: Read in full (verification pass).*

S60 Wikipedia Chisso

Japanese carbide and calcium cyanamide production, Minamata.

https://en.wikipedia.org/wiki/Chisso

*Read status: Read in full (verification pass).*

S61 LeFebure, The Riddle of the Rhine (1921)

Versailles settlement's attention to German chemical strategy; Allied inspection missions "particularly jealous of any inspection at Oppau, the site of the wonderful Haber synthetic ammonia plant"; Haber process's war role.

https://www.fulltextarchive.com/book/The-Riddle-of-the-Rhine-Chemical-Strategy-in/4/

*Read status: site excerpt (multi-page book excerpt).*