RUSI

PROJECT ANTHRACITE

Research and Development Areas to the North of Hamhung

DPRK's Chemical Facilities: Site Profile 4

The Project Anthracite Team

Executive Summary

This report on the Hungnam Fertiliser Complex is the fourth Project Anthracite site profile exploring different chemical production facilities throughout North Korea.[1] The project uses open source information to map out the North Korean chemical industry and its potential links to a chemical weapons programme. The bulk of available information about the Hungnam Fertiliser Complex refers to the production of fertilisers using basic raw materials such as coal, air, water/steam and phosphate ore. Additionally, there is limited information suggesting the site has been used to produce chemical warfare agents (CWAs).

This paper gives a very brief history of the site before going into greater detail around the different areas of the site and the processes that are understood to take place. The paper then provides an assessment of both the chemicals produced on site for their relevance to a potential chemical weapons programme, and whether and how the site would be declarable under the Chemical Weapons Convention (CWC), should North Korea sign and ratify the CWC.

The features and areas of the site are consistent with the large-scale production of fertilisers. The basic raw materials are used to manufacture chemicals including nitrogen, oxygen, carbon dioxide, ammonia and hydrogen, which are in turn used in the production of urea, ammonium nitrate, ammonium phosphate and superphosphate. These are all fertilisers.

While there were no indictors that CWAs are produced on the site, there are several chemicals which are produced on site and which can be used in upstream processes to produce precursors for CWAs.

Acknowledgements

The authors would like to thank the peer reviewers for their valuable feedback and suggestions.

This report was made possible by the support of Global Affairs Canada.

In partnership with Canada

1. For other site profiles and more information about Project Anthracite, see RUSI, 'Project Anthracite: Assessing the Chemical Weapons Capability of the DPRK', <https://www.rusi.org/explore-our-research/projects/project-anthracite-assessing-chemical-weapons-capability-dprk#site-profiles>, accessed 18 July 2025.

Hungnam Fertiliser Complex: DPRK’s Chemical Facilities: Site Profile 4

Project Background

North Korea has long been assessed by many countries as having a chemical weapons (CW) programme. In 2006, a South Korean defence ministry white paper estimated that between 2,500 and 5,000 tons of chemical warfare agents (CWAs) were stored in facilities across the country. This amount was reiterated in a 2022 white paper.[2]

The 2017 assassination of Kim Jong-un’s half-brother Kim Jong-nam with the nerve agent VX,[3] in an attack that was widely accepted as being orchestrated by North Korea,[4] served as a reminder of the longstanding North Korean CW programme and highlighted that very little is known about it, in contrast to the international attention paid to North Korea’s missile and nuclear programmes.[5]

In an attempt to identify means to increase international understanding of North Korea’s CW programme, RUSI published a feasibility study in partnership with the Defence Science and Technology Laboratory (Dstl) in March 2022, which concluded that open source tools could help to understand North Korea’s chemical industry, allowing hypotheses about CW production to be developed and refined.[6] The study formed part of a multi-year project on North Korean WMD in cooperation with VERTIC and the James Martin Center for Nonproliferation Studies.[7]

One of the conclusions of the feasibility study was that:

> Future work will need to consider industrial capability as a network; looking at single sites in isolation will leave knowledge gaps. Although this approach as applied to a single site will help inform assessments of activity taking place there, it will not support a holistic understanding of a CW capability. This is

2. Ministry of National Defence, The Republic of Korea, ‘2022 Defense White Paper’, <https://tinyurl.com/37rx9z2c>, accessed 21 October 2024.
3. Organisation for the Prohibition of Chemical Weapons (OPCW), ‘Statement by H.E. Ambassador Ahmad Nazri Yusof, Permanent Representative of Malaysia to the OPCW at the Eighty-Seventh Session of the Executive Council’, EC-87/NAT.14, 14 March 2018, <https://www.opcw.org/sites/default/files/documents/EC/87/en/ec87nat14_e_.pdf>, accessed 4 January 2024.
4. Hannah Ellis-Petersen and Benjamin Haas, ‘How North Korea Got Away with the Assassination of Kim Jong-nam,’ *The Guardian*, 1 April 2019.
5. See, for example, Nuclear Threat Initiative (NTI), ‘The CNS North Korea Missile Test Database’, 28 April 2023, <https://www.nti.org/analysis/articles/cns-north-korea-missile-test-database/>, accessed 7 May 2023; Hans M Kristensen and Matt Korda, ‘Nuclear Notebook: How Many Nuclear Weapons Does North Korea Have in 2022?’, *Bulletin of the Atomic Scientists*, 8 September 2022, <https://thebulletin.org/premium/2022-09/nuclear-notebook-how-many-nuclear-weapons-does-north-korea-have-in-2022/>, accessed 7 May 2023.
6. Cristina Varriale and Sarah Clapham, ‘Remote Assessment of North Korea’s Chemical Weapons: Feasible or Not?’, RUSI Occasional Papers (March 2022).
7. VERTIC, ‘North Korean Weapons of Mass Destruction Capabilities’, <https://www.vertic.org/programmes/vm/dprk/>, accessed 16 July 2025.

because it is unlikely that an individual facility is responsible for start-to-finish production of CW. [8]

Based on the feasibility study and with the support of Global Affairs Canada, RUSI has initiated Project Anthracite, a three-year project to use open source tools and remote-sensing technologies to provide a networked overview of North Korea's chemical industry, by profiling sites and seeking to understand their role in North Korea's chemical industry as well as any links they might have to CW production.[9]

CW production programmes have predominantly had their roots in the chemical industry, from research into new pesticides to the supply of raw materials and intermediates. Many chemicals which have formed part of historic worldwide CW programmes have been included in the Annex on Chemicals, which forms part of the Chemical Weapons Convention (CWC).[10] This annex defines the basis for allocating one of three schedules to some chemicals. Which schedule is allocated depends on aspects such as toxicity, quantity of use for purposes not prohibited by the CWC, and whether the chemical has been used as a CW or identified as a precursor. For completeness, it should be noted that a chemical can be classed as a CW without being in any of the schedules.

Site Selection

The Hungnam Fertiliser Complex is an important site for North Korea. Generically, fertiliser, whether organic or produced by chemical processes, is vitally important to crop growth.[11] As North Korea has regularly suffered from food shortages, it follows that Hungnam Fertiliser Complex, as a fertiliser production site, would be of great importance to the country.

In addition to producing fertiliser, the complex has also been identified as potentially producing CWAs,[12] lithium 6, which is a raw material used in the production of nuclear weapons,[13] and unsymmetrical di-methyl-hydrazine, which is rocket engine fuel.[14]

While most of the information analysed by the Project Anthracite team focuses on the production of fertiliser and, to an extent, chemicals that would feature in nuclear

8. Cristina Varriale and Sarah Clapham, 'Remote Assessment of North Korea's Chemical Weapons', pp. 31–32.
9. RUSI, 'Project Anthracite: Assessing the Chemical Weapons Capability of the DPRK', <https://rusi.org/explore-our-research/projects/project-anthracite-assessing-chemical-weapons-capability-dprk>, accessed 28 October 2024.
10. OPCW, 'Annex on Chemicals', <https://www.opcw.org/chemical-weapons-convention/annexes/annex-chemicals/annex-chemicals>, accessed 3 May 2023.
11. World Bank Group, 'World Bank's Food for 10 Billion Podcast: Fertilizer Volatility and the Food Crisis', *Table for 10 Billion*, World Bank podcast, 22 July 2022, <https://www.worldbank.org/en/news/podcast/2022/07/22/fertilizer-volatility-and-the-food-crisis>, accessed 23 July 2025.
12. GlobalSecurity.org, 'Weapons of Mass Destruction (WMD): Hungnam, Hungnam Chemical Engineering College, Hungnam Fertilizer Complex', <https://www.globalsecurity.org/wmd/world/dprk/hungnam.htm>, accessed 23 July 2025.
13. David Albright et al., 'North Korea's Lithium 6 Production for Nuclear Weapons', Institute for Science and International Security, 17 March 2027, <https://isis-online.org/isis-reports/detail/north-koreas-lithium-6-production-for-nuclear-weapons/10>, accessed 23 July 2025.
14. Joseph S. Bermudez Jr et al., 'UDMH Production in North Korea: Additional Facilities Likely', 38 North, 25 October 2017, <https://www.38north.org/2017/10/udmh102517/>, accessed 23 July 2025.

proliferation, the site has also been referenced as producing raw materials and intermediates to produce CWAs, if not the agents themselves.

Methodology

The Hungnam Fertiliser Complex is regularly referenced in open sources, which is understandable given the need for fertiliser to improve the output of the North Korean agricultural industry. RUSI reviewed open source information for the site and categorised declassified government intelligence and satellite imagery as primary sources. Information such as think tank analysis and news coverage were classed as secondary sources.

This report features satellite imagery analysis. RUSI used the formalised, well-established imagery analytical approach as trained and adopted by the military imagery analysis community. This approach considers eight factors: location; size; shape; shadow; tone/colour; texture; pattern; and associated features. The information was analysed by an expert consultant. The analysis was subsequently reviewed within the team (which includes satellite imagery experts).

This paper outlines the most likely process descriptions and associated chemistry used at the site, as assessed by chemists and chemical engineers based on research into potential processes and information on Hungnam Fertiliser Complex found in open source information.

The report was also externally peer reviewed, with inputs included as appropriate. The satellite imagery analysis was coupled to the analysis of all the other information to provide overall analysis of the site.

Stills from a YouTube video posted by a North Korean account feature in the report. These videos are no longer accessible 'because the YouTube account associated with this video has been terminated'.[15]

Introduction and Context

The Hungnam Fertiliser Complex is in a highly industrialised area and is one of several chemical sites and industrial facilities in Hamhung and the surrounding area. Project Anthracite has already issued two site reports covering facilities in the area,[16] and a further site report is expected later in the year. The plant site produces a variety of different fertilisers, which will be discussed later in the paper, as well as the chemicals needed to produce those fertilisers.

15. 우리민족 제일 ['Our People are the Best'], '현지방송 집단적혁신의 불길높이 – 흥남비료련합기업소' ['Local Broadcasting Group Innovation Flames High – Heungnam Fertilizer Complex'], YouTube video, video now unavailable, <https://www.youtube.com/watch?v=C9kHRUwkwZY>, accessed 5 July 2023.
16. Lennie Phillips et al., 'New Building in Hamhung Area: North Korea's Chemical Facilities: Site Profile 2', RUSI, 27 February 2024; The Project Anthracite Team, 'R&D Areas North of Hamhung: North Korea's Chemical Facilities: Site Profile 3', 23 July 2025.

Figure 1: The Hungnam Fertiliser Complex

Source: 우리민족 제일 *[Our People are the Best]*, '현지방송 집단적혁신의 불길높이 – 흥남비료련합기업소' *['Local Broadcasting Group Innovation Flames High – Hungnam Fertiliser Complex'], YouTube video, video now unavailable, <https://www.youtube.com/watch?v=C9kHRUwkwZY>, accessed 5 July 2023.*

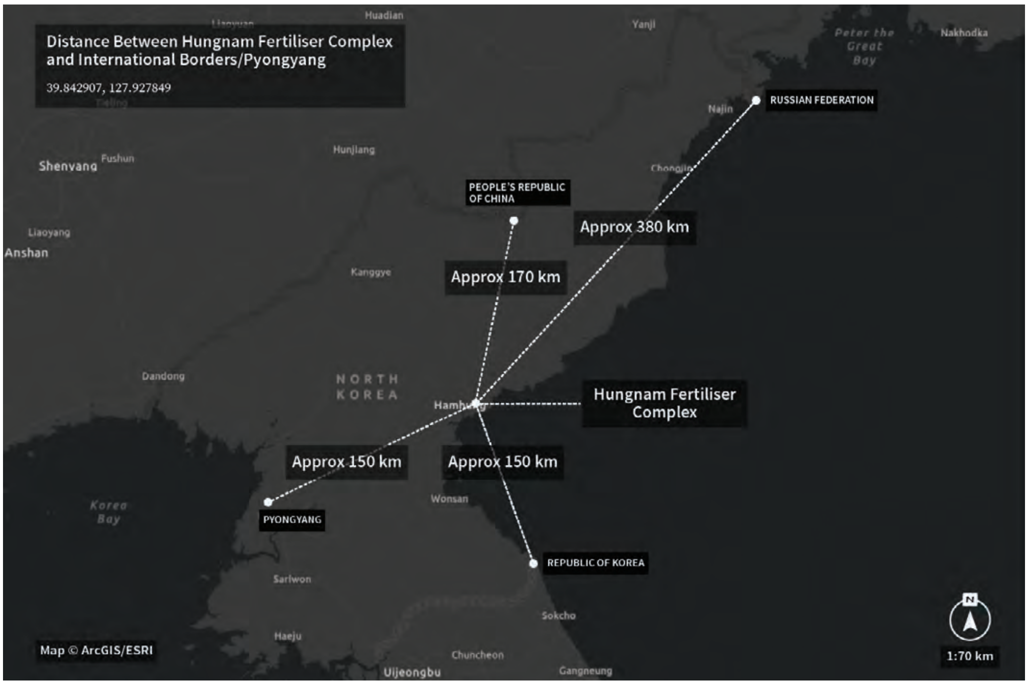
Fertiliser was produced on the site now occupied by Hungnam Fertiliser Complex from the 1930s, when the processes were built based on Japanese technology.[17] The area just outside the southeast corner of the site, referred to as the Hungnam Nonferrous Metals Plant, was bombed in 1950 as it was believed to produce thorium as part of an atomic weapons programme.[18] It is unclear whether the neighbouring fertiliser complex was also targeted in the same conflict. CIA reports indicate that the complex has been operational from at least 1963 onwards.[19]

Throughout the history of the site, various modifications and additions have been made to it; these will be covered in the relevant sections of this paper.

The complex is located at 39°50'27"N 127°37'35"E, close to the coast at an altitude of only a few metres above sea level in the Hungnam district of Hamhung, South Hamgyong Province. The city of Hamhung is heavily industrialised and is the second largest city in North Korea.[20]

17. Bill Streifer, 'Two CIA Reports: Hungnam, North Korea', *American Intelligence Journal*, (Vol. 32, No. 1, 2015), pp. 181–186.
18. *Ibid*.
19. CIA, 'Hungnam Nitrogen Fertilizer Plant, Hungnam, North Korea', Basic Imagery Interpretation Report, June 1969, <https://www.cia.gov/readingroom/docs/CIA-RDP79T00909A000500010020-9.pdf>, accessed 23 July 2025, p. 3.
20. Kyoung Seok Jang and Hyung Min Kim, 'Hamhung, the Second-Largest North Korean City: Dynasty Urbanism, Colonial Urbanism and Socialist Urbanism', *Cities* (Vol. 114, July 2021), <https://www.sciencedirect.com/science/article/abs/pii/S0264275121000895>, accessed 21 July 2025.

Figure 2: Distance Between Hungnam Fertiliser Complex and International Borders/Pyongyang



Source: ArcGIS/ESRI Basemap. Annotated by the authors.

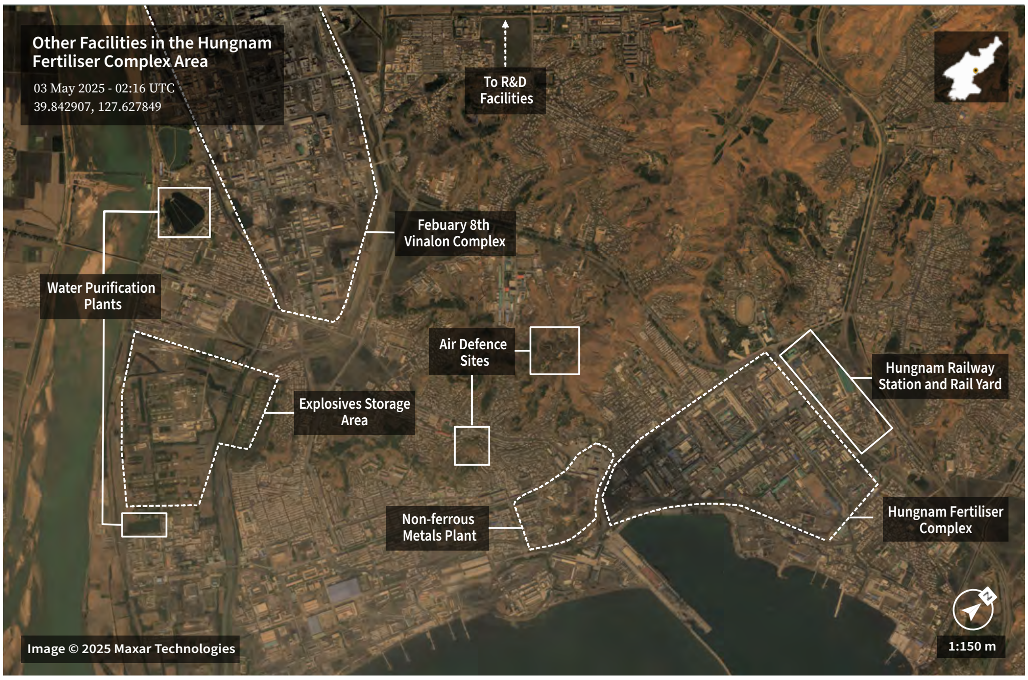
The southern boundary of the site is less than 100m from the sea and adjacent to the port of Hamhung, which is an important conduit for the supply of coal, which is used not only to support power generation for the complex but also as a raw material for some of the processes. Other raw materials may also be routed through the port.

The site is also served by main road and rail – the adjacent Hamhung railway station and sidings are active (see Figure 3). A branch line serves the complex directly and has several spurs that support different functional areas within the facility. These links connect the facility to the nearby February 8th Vinalon Complex (approximately 3 km away) and the Chemical Materials Institute[21] (approximately 12 km away). The Songchon River is the major watercourse in the area and is less than 2 km from the Hungnam Fertiliser Complex.

As shown in Figure 3, the Non-ferrous Metals Plant is adjacent to the site, by the southwestern corner.

21. The Project Anthracite Team, 'Research and Development Areas North of Hamhung', RUSI, 19 November 2024, <https://www.rusi.org/explore-our-research/publications/special-resources/rd-areas-north-hamhung-north-koreas-chemical-facilities-site-profile-3>, accessed 21 July 2025.

Figure 3: Other Facilities in the Hungnam Fertiliser Complex Area



Source: Maxar Technologies, 3 May 2025. Annotated by the authors.

What is Part of the Site?

The main complex is almost completely walled. External to the perimeter wall, the site is bordered immediately by road or railway.

Figure 4 shows the perimeter of the site, including an area outside the boundary wall that is linked by footbridge to a compound (39°50’22”N 127°37’10”E). Imagery shows some sort of structure which appears to be attached to the northeastern side of the footbridge. While it is possible that this is pipework connected to the site, it is more likely some sort of signage or gantry.

The footbridge itself links the site to a compound. This compound has been identified on a North Korean map from 2012[22] as the Hungnam University of Industry. The footbridge suggests a very strong link between the plant site and the university, and as such, the authors have included it as being part of the plant site.

22. 2012 atlas of North Korea 조선지도첩 (2012). Source was provided by 38 North, which accessed the information on 22 July 2025.

Figure 4: Hungnam Fertiliser Complex Perimeter and Main Area

Source: Maxar Technologies, 3 May 2025. Annotated by the authors.

On the northwest perimeter, there are three places where pipework crosses the road and railway. These are shown in Figure 5. The broken red lines in the inset image highlight the pipework. The three pipelines are explored in more detail below.

Figure 5: Pipework Crossing Site Boundary

Source: Maxar Technologies, 3 May 2025. Annotated by the authors.

From imagery alone, it is not possible to determine the fluid in these pipelines, nor the direction of travel. They probably contain generic streams such as nitrogen, air, water, steam and so on, and are unlikely to be particularly hazardous. The following points give brief descriptions of the pipeline routes.

1. 39°50’26”N 127°37’14”E: From here, pipework takes a somewhat circuitous route of over 5 km to 39°49’24.5”N 127°35’21.1”E, which is approximately 3 km away as the crow flies. Using the satellite imagery that was available to the team, it was not possible to assess the direction of travel of fluids in the pipework, determine which area of the Hungnam Fertiliser Complex was connected to the pipework, or have a strong degree of certainty about to what the other end of the pipe was connected.

   The route taken by the pipework is notable because it avoids residential and built-up areas. The reason for this chosen routing is unclear, but there are several different possibilities. These possibilities include:

- There were branches off this pipework that have either been decommissioned or dismantled.
- There were branches that have not been spotted on the available imagery.
- The fluid in the pipe is hazardous, and the route has been designed to reduce impact on people in the event of loss of containment.

Satellite imagery from Google Earth appears to show piping crossing the river at 39°50’09.6”N 127°37’12.6”E and entering the 8th February Vinalon Complex before 2010. This piping branches away from the main pipe track, which continues in a southerly direction at this point. It is not clear whether this is separate pipework or whether it branches off other pipework. From 2010, this branch to the Vinalon Complex appears be in a progressing state of disrepair, until it is no longer visible from 2012 onwards.

2. 39°50’19”N 127°37’06”E: The piping appears to route underground close to a pipe bridge.
3. 39°50’18”N 127°37’05”E: It is not clear from satellite imagery whether this pipework leads into a building that is adjacent to the plant site or whether it also leads underground.

Hungnam Fertiliser Complex: Site Overview

The site is approximately 100 hectares in area and comprises several relatively self-contained areas used for chemical manufacture, as well as amenities and other areas of site infrastructure.

In 1998, reference was made to the site having more than 50 workshops.[23] These workshops are not all chemical plants and include infrastructure. Those workshops that are associated with chemical manufacture are not necessarily individual chemical production plants, with some workshops more likely being operated as part of a larger plant.

The following areas, units and workshops are referenced in North Korean sources:[24]

- Gas Generator Workshops
- Gas Purification Workshops
- Urea Workshop
- Chemical Machinery Branch Factory
- Maintenance Branch Office
- Technology Department

23. Lee Chae-sung, *Technocrats Who Are Moving North Korea* (Seoul: Ilbit, 1998).
24. ‘Highly Upholding the Revolutionary Platform of Rural Revolution in the New Era, the Struggle for Increased Fertilizer Production Is Being Waged Vigorously: Functionaries and the Working Class of the Hungnam Fertilizer Complex’, *Rodong Sinmun*, 27 March 2023, <http://www.rodong.rep.kp/ko/index.php?OEAyMDIzLTAzLTI3LU4wMDJANEBAQDFAMQ==>, accessed 4 July 2023; ‘To What Are We Attaching Importance in Adjustment, Reinforcement, and Production Guidance?’ *Rodong Sinmun*, 15 March 2023, <http://www.rodong.rep.kp/ko/index.php?OEAyMDIzLTAzLTE1LU4wMTlAMkBAQDFAMTk=>, accessed 4 July 2023; ‘Day After Day of Innovation in Juche Fertilizer Production: At the Hungnam Fertilizer Complex’, *Rodong Sinmun*, 12 February 2023, <http://www.rodong.rep.kp/ko/index.php?OEAyMDIzLTAyLTEyLU4wMDRANEBAQDFAMw==>, accessed 23 June 2023; ‘The Demands of the Party and the Revolution Are Our Goal and Practice: Officials and Working Class of Hungnam Fertilizer Complex Expanding Fertilizer Production Performance with the Momentum of Adhering to the Party’s Equipment and Reinforcement Strategy and Finishing the Facility Intensive Repair Ahead of Time’, *Rodong Sinmun*, 1 November 2022, <http://www.rodong.rep.kp/ko/index.php?OEAyMDIyLTExLTAxLU4wMTBANEBAQDFAMQ==>, accessed 23 June 2023; ‘Hungnam Fertilizer Complex, Various Construction Units Actively Promote Fertilizer Production Capacity Expansion Project’, *Rodong Sinmun*, 27 September 2021, <http://uriminzokkiri.com/index.php?ptype=cgisas&mtype=view&no=1216678>, accessed 23 June 2023; North Korea Leadership Watch, ‘Visit to Major Industrial Sites in Hamhung’, <https://www.nkleadershipwatch.org/kci-2011-public-apperances-2/visit-to-major-industrial-sites-in-hamhung/>, accessed 23 July 2025.

- Desulfurisation Unit
- Waste Gas Treatment Unit
- Water Electrolysis Plant
- Compressor Workshop
- Nitrogen Workshop
- Repair Workshop
- Design Office
- Industrial Technical Laboratory
- Catalyst Laboratory
- Electric Conversion Workshop
- Sulfuric Acid Workshop
- Superphosphate Workshop
- General Staff Department

Specific mention is made of Gas Generator Workshop No. 1 and Gas Generator Workshop No. 3 (suggesting that there may also be workshop No. 2). The chemical branch workshop includes a High Frequency Workshop, Steel Casting Workshop, Preparation Workshop, Processing Workshop No. 1, and Processing Workshop No. 2. Nitrogen Workshop No. 2 is specifically mentioned, suggesting that there may be at least two nitrogen workshops. Similarly, Repair Workshop No. 2 is specifically mentioned, suggesting that there are at least two repair workshops. Additionally, one source refers to a research team being sent to Hungnam Fertiliser Complex to help in the production of melamine. [25]

References also include chemicals produced on the site as follows:[26]

- Urea
- Nitrogen
- Ammonium sulfate
- Ammonium nitrate
- Ammonia solution
- Sulfuric acid
- Superphosphate fertiliser
- Nitric acid
- Ammonium phosphate
- Melamine
- Catalysts for ammonia synthesis
- Crude benzole (and other organic chemicals)
- Methanol

The main access point for large vehicles appears to be at 39°50’12”N 127°38’3”E. There is a gatehouse, but there is no visible evidence of physical access control. A second access point, at 39°50’34”N 127°37’40”E, has a related gatehouse and appears to have physical access control; this appears to be the main entrance for the site. There are no apparent physical means to control rail access to the site.

25. DPRK Today, ‘Strengthened Roles of Researchers of the State Academy of Sciences’ Hamhung Branch Sent to Major Units’, 3 March 2023, <https://dprktoday.com/news/63964>, accessed 4 July 2023.
26. *Foreign Trade of the Democratic People’s Republic of Korea* (FTDPRK), ‘Hungnam Fertiliser Complex’, (No. 4, 2016), p. 26; Song Ryo Myong, ‘New Methanol Production Process Built’, Korea Today (No. 6, 2013), p. 19.

The basic raw materials for the site are water, coal and air. Between them, they provide the elements hydrogen, nitrogen, carbon (as carbon dioxide), oxygen and sulfur (as hydrogen sulfide), which are used to produce other chemicals on site. The production areas are highly inter-related; products or side streams from one process are utilised in other processes. The site takes these basic raw materials and converts them into fertilisers. The principal fertiliser produced in the site is urea, which is formed from the reaction of carbon dioxide with ammonia to produce ammonium carbamate, which is then broken down to give urea and water. These processes are covered in greater detail later in this paper.

The site is split into several distinct areas, some of which are clearly used for chemical manufacture and supporting infrastructure, and others the purpose of which is not as apparent. There appears to be a logical flow of the main manufacturing areas on the western side of the site, moving from the south, where the coal is delivered, to the north, where urea is produced. Other manufacturing areas are located to the east of these areas.

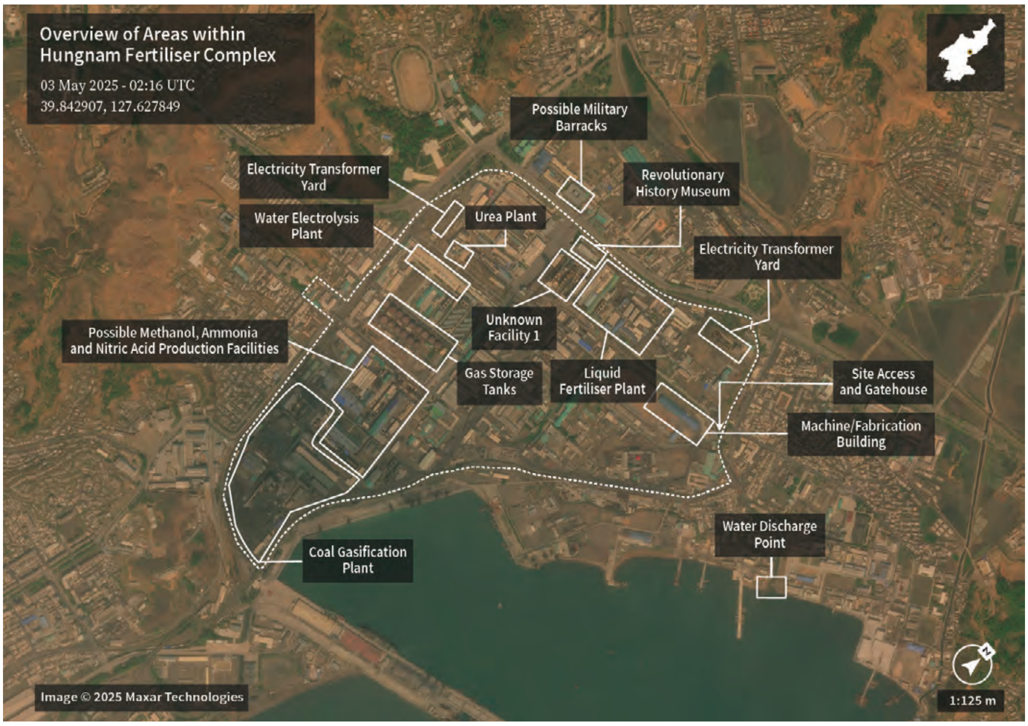
There is also one large tank farm comprising 15 gasometers, which are used for the storage of gases at ambient conditions.

Several processes undertaken at the site require either nitrogen or oxygen, suggesting that air is a key feedstock. While it is theoretically possible to remove oxygen from air, by its reaction in one process (leaving unreacted nitrogen available to be used for another process and vice versa), this is not a pragmatic approach for producing the variety of chemicals on site and there would need to be a very close relationship between the production quantities of different chemicals at the site. It therefore follows that there will be units on site for the manufacture of nitrogen and oxygen. In addition to the route outlined above of producing nitrogen and oxygen by their separation from air, it is also possible to electrolyse water to produce oxygen and hydrogen. Typically, electrolysis of water is not utilised in industrial processes due to its relative cost compared to other processes. However, sources indicate the presence of a water electrolysis plant on the site, which is likely to be run in tandem with an air separation unit to provide flexibility in relative quantities of raw materials.[27]

Figure 6 gives an overview of the different areas in Hungnam Fertiliser Complex.

27. North Korea Leadership Watch, 'Visit to Major Industrial Sites in Hamhung'.

Figure 6: Overview of Areas within Hungnam Fertiliser Complex



Source: Maxar Technologies, 3 May 2025. Annotated by the authors.

It has not been possible, in all cases, to correlate the likely individual processes to a particular area of the plant site. In these cases, processes and areas of the plant site will be described separately.

Hungnam Fertiliser Complex: Manufacturing Areas

It should be noted that all the processes described in this section are typical industrial processes used to produce fertilisers.

Coal Gasification Plant, including the Air Separation Unit

This plant is in the western corner of the plant site at 39°50’10”N 127°37’14”E. It is used to turn the solid coal into a mixture of gases which in turn can be used elsewhere on the site.

A review of Google Earth satellite imagery indicated significant construction on a new gasification plant between April 2010 and March 2011. Figure 7 shows imagery of the gasification plant from March 2007. It had been demolished by October 2009. New gasifiers were constructed, along with what appear to be an air separation unit, a water electrolysis unit and associated storage. The water electrolysis unit supplements a previously existing plant (covered later in the report), while the air separation unit provides additional operational flexibility for the plant site.

Figure 7: Gasification Plant Modifications

Sources: Google Earth (Maxar Technologies and Airbus), 9 March 2007 and 3 December 2019. Annotated by the authors.

In mid-2020, a third gasifier was constructed in this area, along with an additional boiler, as shown in Figure 8.[28]

28. Joseph S Bermudez Jr and Dana Kim, 'Hungnam Fertilizer Complex Update: Strategic Modernization for Multi-Purpose Use?', 8 September 2020, <https://beyondparallel.csis.org/hungnam-fertilizer-complex-update-strategic-modernization-for-multi-purpose-use/>, accessed 23 July 2025.

Figure 8: Addition of a New Gasifier

Sources: Google Earth (Maxar Technologies), 3 December 2019, prior to installation of third gasification tower, and Maxar Technologies, 3 May 2025, showing the third gasification tower. Annotated by the authors.

Coal is supplied to the site by rail, most probably from coal deposits in the region.[29] There is also evidence of coal storage areas in the adjacent port, which may also be used to supply the site.

The coal gasification plant also requires oxygen as a raw material. Air contains approximately 21% oxygen, with the remaining content being mainly nitrogen.

Some of the downstream processes at Hungnam Fertiliser Complex require either nitrogen or oxygen. The purity of nitrogen and oxygen is a significant factor in operating some of the technology that might be used at Hungnam Fertiliser Complex. For example, in the production of ammonia, it is important to have a very low oxygen content in the nitrogen feedstock, whereas nitrogen in the oxygen used for the gasification of coal or to produce sulfuric acid would have a relatively minimal impact.

As mentioned previously, a variety of different processes can provide a source of oxygen and/or nitrogen from air for the other processes on site. The oldest technology is known as cryogenic air separation (distillation),[30] but air can also be separated by pressure swing adsorption and membrane gas separation.[31]

29. Charles Kraus and Evan Pikulski, 'The Coal Hard Truth', Wilson Center, 27 February 2017, <https://www.wilsoncenter.org/blog-post/the-coal-hard-truth>, accessed 23 July 2025.
30. National Energy Technology Laboratory (NETL), 'Commercial Technologies for Oxygen Production', <https://www.netl.doe.gov/research/Coal/energy-systems/gasification/gasifipedia/commercial-oxygen>, accessed 23 July 2025.
31. NiGen, 'How to Separate Nitrogen from Air', <https://nigen.com/how-separate-nitrogen-from-air-ways-extract-nitrogen/>, accessed 15 August 2023; Ross Thompson, 'Pressure Swing Adsorption (PSA) vs Membrane', 29 September 2023, <https://www.apexgasgenerators.com/post/psa-v-membrane>, accessed 23 July 2025.

Ragwon Machine Complex produces oxygen separators which have been installed at Hungnam Fertiliser Complex.[32] Indications are that Ragwon Machine Complex produces large-scale vessels like those used in distillation processes, as well as machinery that would be consistent with small-scale pressure swing adsorption.[33]

Given the age of the site, and both the quantities of oxygen and nitrogen required and their purity levels,[34] it seems likely that oxygen and nitrogen would be manufactured by cryogenic air separation. This is, in principle, distillation – which, in simple terms, relies on the different boiling points of different chemicals to enable them to be separated from each other. The size and number of distillation columns depend on required flowrates of final products as well as their purity.

The air separation unit is most likely to be co-located with the coal gasification plant in the western corner of the plant site, which conveniently places all the main raw material treatment equipment in one area of the site. Cylindrical vessels at 39°50’06.3”N 127°37’13.6”E have features that are consistent with storage of chemicals at elevated pressures, which would be associated with the storage of nitrogen and oxygen rather than of other gases relevant to the coal gasification plant.

Oxygen is supplied from water electrolysis facilities, with one possibly being located at 39°50’09.6”N 127°37’12.6”E, in the vicinity of the air separation unit. This is labelled 2 on Figure 9. Another possible water electrolysis unit is indicated later in this paper.

Figure 9 shows a photograph of the likely nitrogen/oxygen storage tanks (labelled 4) and their location on satellite imagery. The labels 1–4 in Figure 9 are flagged for geolocation rather than to specifically identify equipment.

32. ‘Ragwon Machine Complex’, *Foreign Trade of the Democratic People’s Republic of Korea* (FTDPRK) (No. 1, 2018), pp. 6–7.
33. *Foreign Trade of the Democratic People’s Republic of Korea* (FTDPRK) (No. 1, 2013), pp. 26–27.
34. Helen Griffin, ‘Air Separation: Cryogenic or Not?’, *The Chemical Engineer*, 28 March 2018, <https://www.thechemicalengineer.com/features/air-separation-cryogenic-or-not>, accessed 23 July 2025.

Figure 9: Photographic Image of Likely Nitrogen/Oxygen Storage Tanks and Their Location

Sources: Satellite imagery from Maxar Technologies, 3 May 2025, and photograph from Foreign Trade of the Democratic People's Republic of Korea (FTDPRK) (Issue 4, 2016), p. 26. Annotated by the authors.

In addition to the high-pressure storage tanks, other equipment includes cooling towers, conveyors, a coal storage area, distillation columns, vents, storage tanks, buildings and other covered areas. A spur of the railway enters one building, which may be used for the storage and maintenance of locomotives.

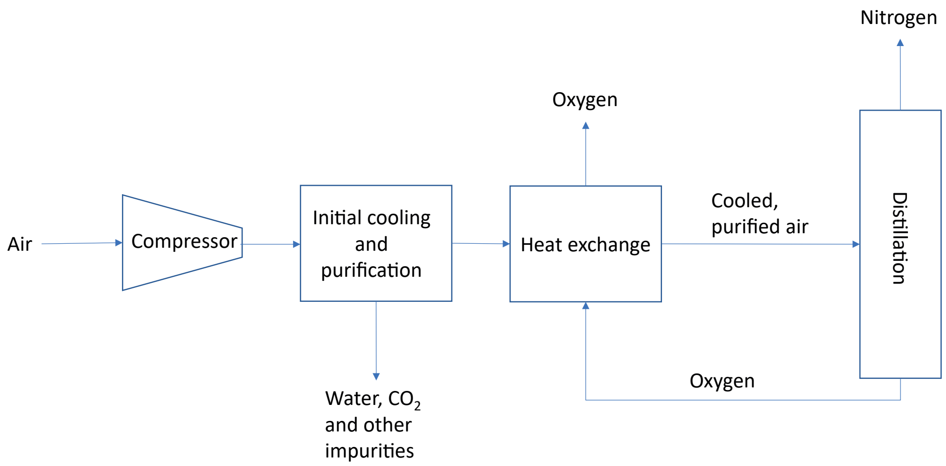
Figure 10: Coal Gasification Plant

Source: Maxar Technologies, 3 May 2025. Annotated by the authors.

Separation of air by distillation requires a blend of low temperature and elevated pressure to facilitate the distillation process, which requires liquid–vapour contact. Such conditions would freeze carbon dioxide and water vapour present in the air, and thus, to avoid process problems, carbon dioxide and water would need to be removed before the main processing steps take place.

A simplified depiction of the typical process for the separation of air is shown in Figure 11.

Figure 11: Simplified Depiction of the Typical Process for the Manufacture of Oxygen and Nitrogen from Air



Source: Based on Satyendra, 'Cryogenic Process of Air Separation', Ispat Guru, 20 July 2013, <https://www.ispatguru.com/cryogenic-process-of-air-separation/>, accessed 18 July 2025.

Oxygen is subsequently used in the coal gasification process, as well as to produce other chemicals on site, while nitrogen is used to produce ammonia and ultimately, urea.

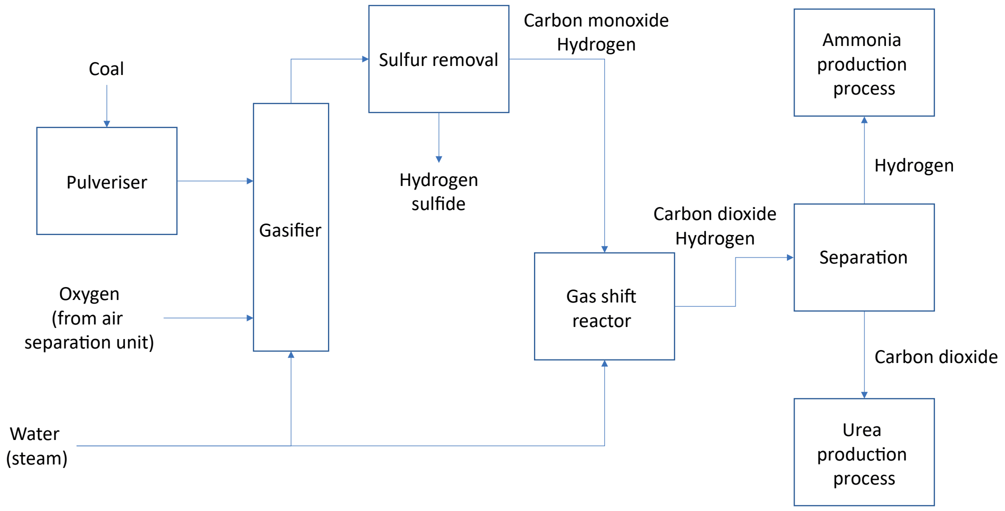
Most of the coal mined in North Korea is anthracite, but lignite is also mined.[35] Both lignite and anthracite have been identified as the types of coal used in the gasification plant.[36] Anthracite is higher quality coal with a higher carbon content and higher energy output. However, although carbon, in the form of carbon dioxide (CO_2), is a raw material to produce urea, carbon content is not the only factor in selecting which type of coal might be utilised. Other factors include the relative value of anthracite when exported due to its greater energy value for power generation and domestic fuel, and the fact that lignite is easier to crush (the first part of the gasification process as outlined in the following text).[37] However, the provision of a schematic of some of the processes on Hungnam Fertiliser Complex to Peter Hayes in 1993,[38] which included briquetting of anthracite, makes a compelling case for the use of anthracite over lignite in the process, particularly as coal of a smaller particle size is less practical for export or for use in domestic heating.

Generically, process steps, equipment and operating parameters are dictated by the composition of the coal feedstock and the purpose of the gases, once produced. To produce urea, the relevant chemicals from this process are carbon dioxide and hydrogen, and thus the gasification process will have been designed and operated towards maximising the production of those two gases.

The first stage of the process involves crushing the coal, followed by the reaction of oxygen (from air), steam and crushed coal at high temperature and pressure, to produce predominantly carbon monoxide and hydrogen as well as small amounts of other gases. This stream is generically known as syngas. Sulfur is removed from this stream as hydrogen sulfide, which not only provides a source of sulfur for other processes at the site but also is a necessity to avoid the poisoning of catalysts in downstream processes. The gases in this stream are predominantly carbon monoxide and hydrogen. Part of this stream can be diverted to the methanol plant, to produce methanol. The rest of the stream then undergoes further reaction (known as the water gas shift reaction or shift conversion) with steam to produce carbon dioxide and hydrogen.[39] Carbon dioxide and hydrogen are separated by the removal of carbon dioxide from this stream by its dissolution in water, most likely under pressure. The hydrogen is probably stored in gasometers before being used to produce ammonia, and the carbon dioxide stored in water under pressure before being used in the production of urea.

35. USGS, ‘2019 Minerals Yearbook: North Korea [Advance Release]’, <https://pubs.usgs.gov/myb/vol3/2019/myb3-2019-north-korea.pdf>, accessed 23 July 2025, p. 14.4.
36. Joseph S Bermudez Jr and Victor Cha, ‘Kim Zeroes in on Fertilizer Production: The Latest Activity at the Hungnam Liquid Nutrient Fertilizer Factory’, Beyond Parallel, <https://beyondparallel.csis.org/kim-zeroes-in-on-fertilizer-production-the-latest-activity-at-the-hungnam-liquid-nutrient-fertilizer-factory/>, accessed 23 July 2025; David von Hippel and Peter Hayes, ‘DPRK Investments in Coal Gasification Driven by Long-Run Juche and Sanctions Proofing’, NAPSNet Special Report, Nautilus Institute, 6 February 2019, <https://nautilus.org/napsnet/napsnet-special-reports/dprk-investments-in-coal-gasification-driven-by-long-run-juche-and-and-sanctions-proofing/>, accessed 23 July 2025.
37. Ji Wang et al., ‘Characterization of Slag from Anthracite Gasification in Moving Bed Slagging Gasifier’, *Fuel* (Volume 292, 15 May 2021); Krystal, ‘What is the Difference Between Lignite and Anthracite?’, OFTRB, 3 February 2024, <https://www.oftrb.com/archives/11696>, accessed 21 July 2025.
38. von Hippel and Hayes, ‘DPRK Investments in Coal Gasification Driven by Long-Run Juche and Sanctions Proofing’.
39. NETL, ‘Gasification Introduction’, <https://netl.doe.gov/research/Coal/energy-systems/gasification/gasifipedia/intro-to-gasification>, accessed 23 July 2025.

Figure 12: Simplified depiction of process steps in the Coal Gasification Plant



Source: David von Hippel and Peter Hayes, 'DPRK Investments in Coal Gasification Driven by Long-Run Juche and Sanctions Proofing', NAPSNet Special Report, Nautilus Institute, 6 February 2019, <https://nautilus.org/napsnet/napsnet-special-reports/dprk-investments-in-coal-gasification-driven-by-long-run-juche-and-and-sanctions-proofing/>, accessed 30 May 2023.

In 2016, it was reported that the complex had established 'lines to treat waste gas and obtain crude benzole and other organic matters'.[40] This suggests that chemicals that were previously vented to atmosphere are now recovered and probably used as fuel.

In recent years, a third gasification tower was constructed,[41] thus increasing the production capacity for carbon monoxide, hydrogen and hydrogen sulfide. While the intention may have been to fill potential existing capacity in the shift reaction stage, this would have meant an original over design in the shift reaction part of the process and would seem unlikely. More likely, the additional production capacity of the gasification plant would be used to produce organic chemicals, mainly hydrocarbons, which could be used in the manufacture of fuels or as building blocks for the chemical industry. There do not appear to be associated new builds on site that could be related to the production of such chemicals. It is therefore likely that they are transported to other sites, possibly by pipeline, where further reaction can take place.

Ammonia and Methanol Production Facilities

These production facilities are in roughly the same area of the site (shown later in Figure 14). Given both the similar equipment used by these two types of facility and the resolution of satellite imagery, it has not been possible to distinguish with a great degree of certainty which equipment belongs to the methanol facility and which to the ammonia facility. These facilities are located to the north of the coal gasification plant and air separation unit.

The methanol facility is fed by the carbon monoxide and hydrogen stream from the coal gasifiers, as mentioned previously. This stream may also be supplemented by hydrogen

40. *Foreign Trade of the Democratic People's Republic of Korea* (FTDPRK) (Issue 4, 2016), p. 26.
41. Bermudez Jr and Kim, 'Hungnam Fertilizer Complex Update: Strategic Modernization for Multi-Purpose Use?'.

from the water distillation unit. Several reactions take place to produce methanol (CH_3OH); the following three are the most relevant:[42]

$$2H_2 + CO \rightarrow CH_3OH$$

$$CO_2 + H_2 \rightarrow CH_3OH + H_2O$$

$$CO + H_2O \rightarrow CO_2 + H_2$$

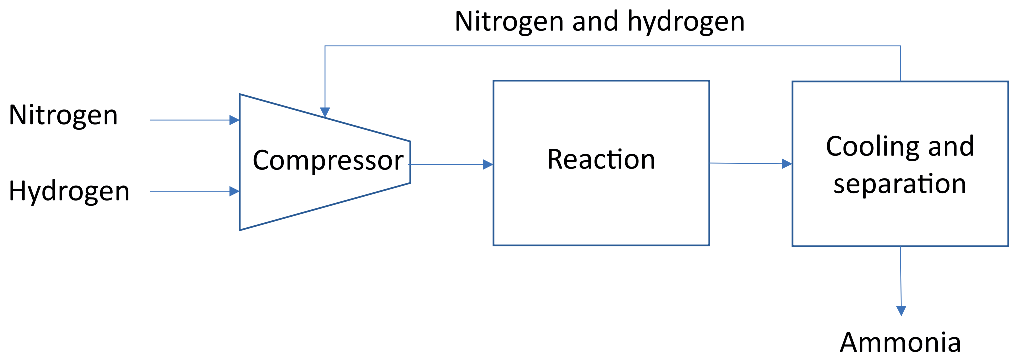
The Project Anthracite team has not been able to identify a use for methanol elsewhere on the site, and in particular how it might be used in the production of fertilisers.

The ammonia facility is used to react nitrogen from the air purifying unit with hydrogen, which is produced in both the water electrolysis plant and the coal gasification plant, to produce ammonia (NH_3). It is important that the oxygen levels in the nitrogen are nominally zero, to avoid an unwanted side reaction of hydrogen with oxygen to produce water, resulting in a reduction in process efficiency.

The reaction takes place at high temperature and high pressure. The parameters of the reaction result in a proportion of unreacted hydrogen and nitrogen which is separated from the ammonia product and recirculated back through the reaction process (see Figure 13). Ammonia is typically stored as a liquid, either under pressure at ambient temperature or below -33°C.[43]

Given the conditions appropriate for the storage of ammonia, the bulk storage tanks are likely to be at least covered, and possibly located in a building to avoid direct sunlight. They are probably stored within the large, covered area 39°50'13"N 127°37'12"E.

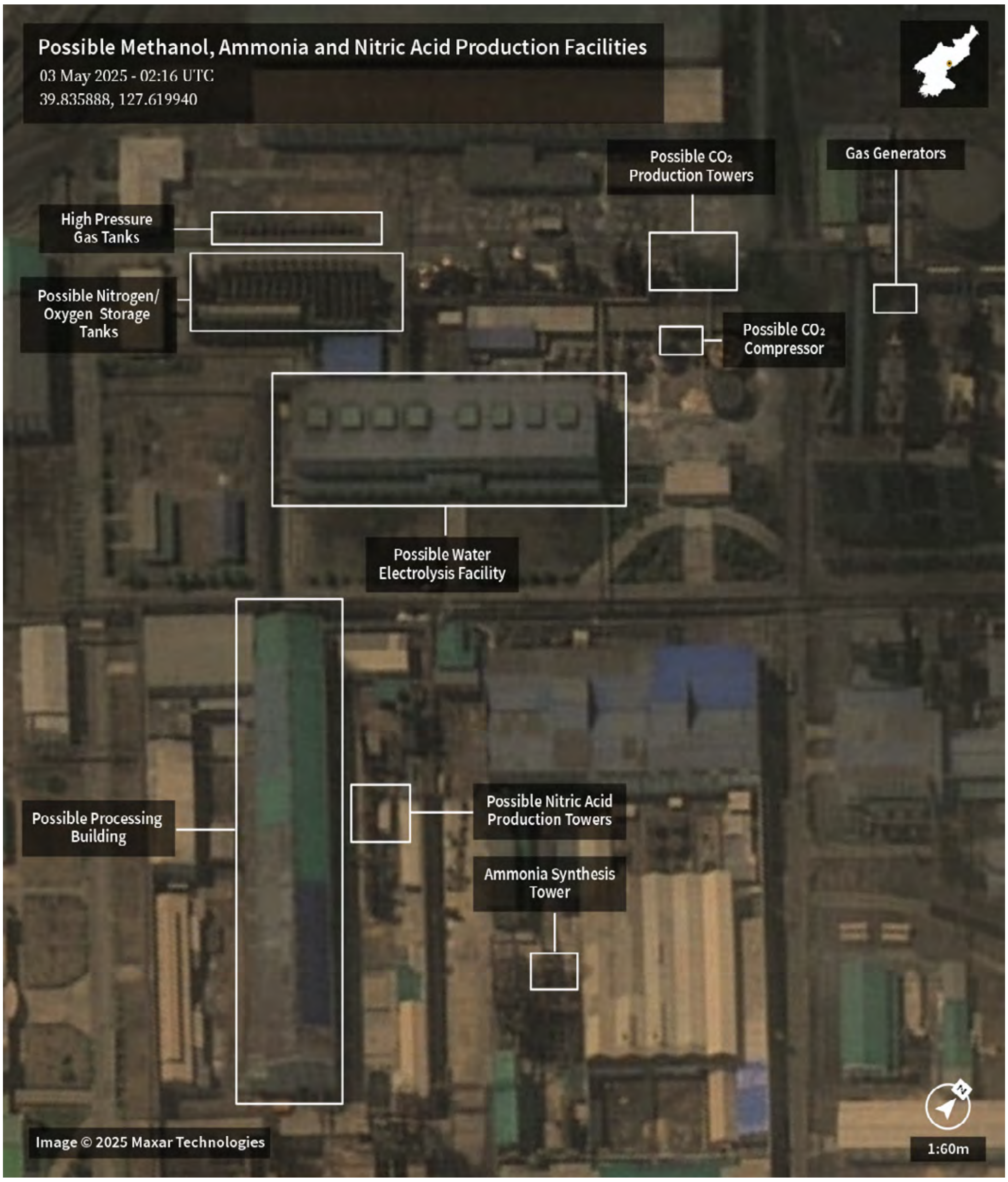
Figure 13: Simplified Depiction of Process Steps in the Ammonia Plant



Source: Based on Izzat Iqbal Cheema and Ulrike Krewer, 'Operating Envelope of Haber–Bosch Process Design for Power-to-ammonia', 11 October 2018, RSC Advances (No. 8, 2018), pp. 34, 926–36.

42. NETL, 'Syngas Conversion to Methanol', <https://www.netl.doe.gov/research/carbon-management/energy-systems/gasification/gasifipedia/methanol>, accessed 27 June 2025.
43. Venkat Pattabathula, Raghava Nayak and Don Timbres, 'Ammonia Storage Tanks', AmmoniaKnowHow.com, <https://ammoniaknowhow.com/ammonia-storage-tanks/>, accessed 21 July 2025.

Figure 14: Possible Methanol, Ammonia and Nitric Acid Production Facilities



Source: Maxar Technologies, 3 May 2025. Annotated by the authors.

From satellite imagery, most of the area is occupied by buildings and roofed structures, but it is also possible to see plant structures containing process equipment which includes various columns, stock tanks and implied other equipment.

Nitric Acid Plant

The nitric acid plant is probably located just east of the ammonia plant at 39°50’12.2”N 127°37’18.4”E and is used to produce nitric acid from ammonia and air. This overall reaction takes place in several reaction stages. The first stage is the high-temperature catalysed reaction of oxygen (in air) and ammonia to produce nitric oxide:

$$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$$

The temperature of the resultant gas, which also includes nitrogen, unreacted oxygen and nitrous oxide (N_2O), is lowered; additional air is introduced and conditions controlled to favour the formation of nitrogen dioxide and its dimer, dinitrogen tetroxide:

$$2NO + O_2 \rightarrow 2NO_2 \leftrightarrow N_2O_4$$

Formation of nitric acid takes place following the dissolution of nitrogen dioxide and dinitrogen tetroxide in water, as indicated by the reactions below:

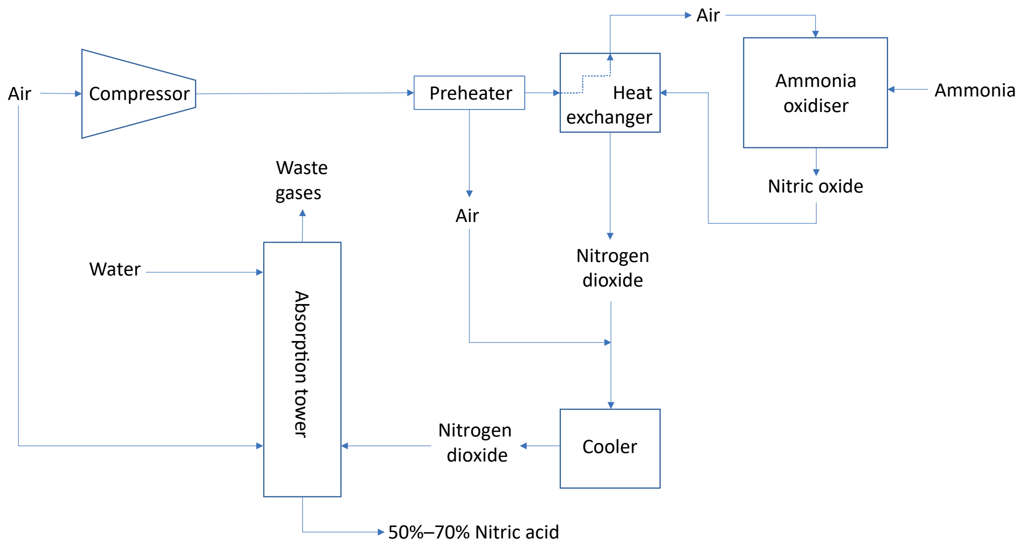
$$3NO_2 + H_2O \rightarrow 2HNO_3 + NO$$

$$3N_2O_4 + 2H_2O \rightarrow 4HNO_3 + 2NO$$

Further air is also introduced at this stage to re-oxidise the nitric oxide and to remove nitrogen dioxide from the nitric acid product.[44]

These steps are shown in Figure 15.

Figure 15: Simplified Typical Process Steps to Produce Nitric acid



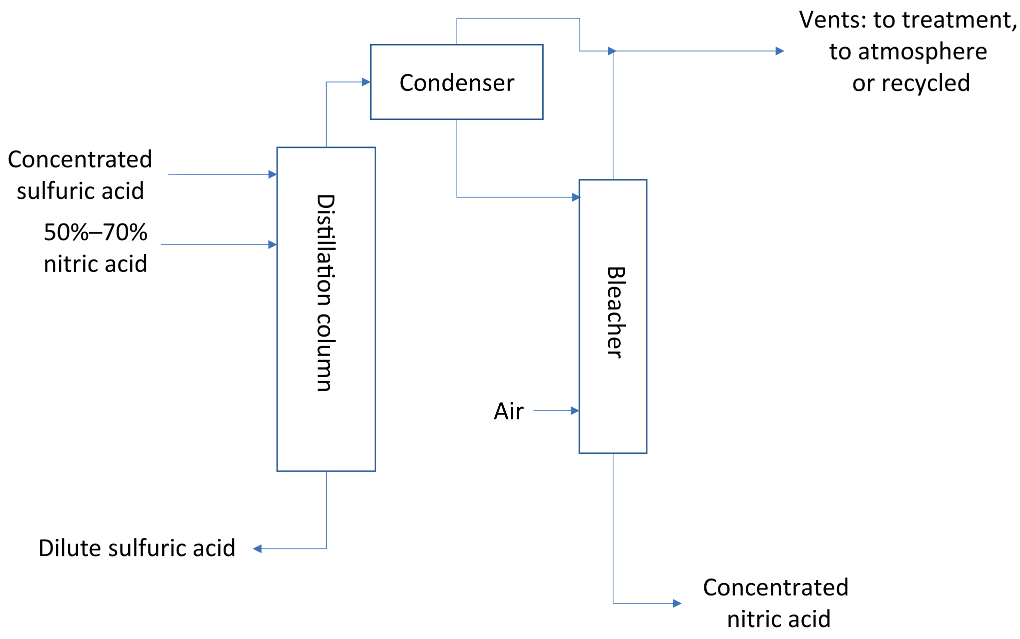
Source: Based on United States Environmental Protection Agency, 'AP-42: Compilation of Air Emissions Factors from Stationary Sources', Fifth Edition (Volume 1, Chapter 8.8), <https://www.epa.gov/sites/default/files/2020-09/documents/8.8_nitric_acid.pdf>, accessed 18 July 2025.

The concentration of nitric acid produced in this process is more than adequate for its use in the production of fertilisers. However, any nitric acid used in the production of explosives would typically need to be of a higher concentration. The concentration of nitric acid can be increased by extractive distillation. Typically, this purification step is carried out using sulfuric acid, which is also understood to be produced on the site (this is covered later in this paper).

Sulfuric acid and nitric acid (50–70% in water) are fed to a distillation column. The concentrated nitric acid, exiting the top of the column, is condensed and fed to a bleacher where air is used to remove nitrogen dioxide from the concentrated nitric acid product.[45]

44. United States Environmental Protection Agency, 'AP-42: Compilation of Air Emissions Factors from Stationary Sources', Fifth Edition (Vol. 1, Chapter 8.8), <https://www.epa.gov/sites/default/files/2020-09/documents/8.8_nitric_acid.pdf>, accessed 18 July 2025.
45. Ablaze, 'Nitric Acid Concentration Plant, <https://www.ablazeexport.com/nitric-acid-concentration-

Figure 16: Simplified Process Steps to Manufacture Concentrated Nitric Acid



Source: Based on Ablaze, 'Nitric Acid Concentration Plant', <https://www.ablazeexport.com/nitric-acid-concentration-plant/>, accessed 23 July 2025.

It is not clear where the unit for concentrating nitric acid might be located, although it is probably co-located as part of the nitric acid plant.

Water Electrolysis Plant

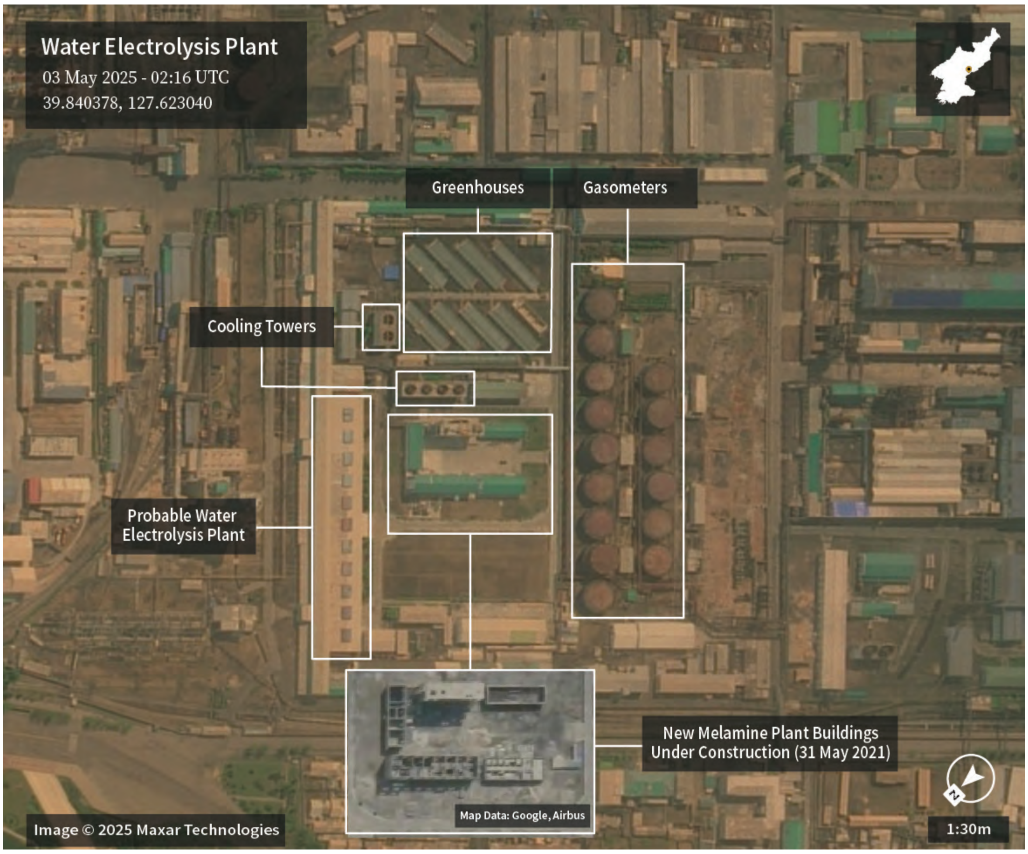
The water electrolysis plant is probably located in the building at 39°50'28.3"N 127°37'22.9"E (see Figure 17). Prior to 2011, this was the only water electrolysis plant on the site. An additional water electrolysis plant was covered in the previous section on the Coal Gasification Plant.

The water electrolysis process uses an electric current to break down water into its constituent molecules, namely oxygen and hydrogen. Typically, this occurs in the presence of an alkaline electrolyte to produce oxygen and hydrogen at different electrodes. The oxygen and hydrogen are collected separately. The hydrogen is likely to be stored in gasometers, whereas the oxygen would be compressed/liquefied for storage.[46]

plant/>, accessed 23 July 2025.

46. U.S. Department of Energy, 'Hydrogen Production: Electrolysis', <https://www.energy.gov/eere/fuelcells/hydrogen-production-electrolysis>, accessed 21 July 2025.

Figure 17: Water Electrolysis Plant and Melamine Plant



Sources: Maxar Technologies, 3 May 2025, and Google Earth (Airbus), 31 May 2021 (inset). Annotated by the authors.

Melamine Plant

The melamine plant is a relatively new construction on the fertiliser complex. Although melamine can be used as a fertiliser, the plant, according to North Korean media, is being used to produce melamine resin.[47] Perhaps melamine is both used as a fertiliser and as feedstock for the resin. Figure 17 shows the location of the melamine plant, located between the probable water electrolysis plant and the gasometers.

Melamine is produced by the breakdown of urea at elevated temperature and pressure. This reaction produces a large quantity of off-gas – ammonia and carbon dioxide – which, once separated from the melamine, can be recycled as feedstocks to the urea plant.

The reaction proceeds as one of the two pathways below.[48] Functionally, however, the feedstocks and reaction conditions are the same.

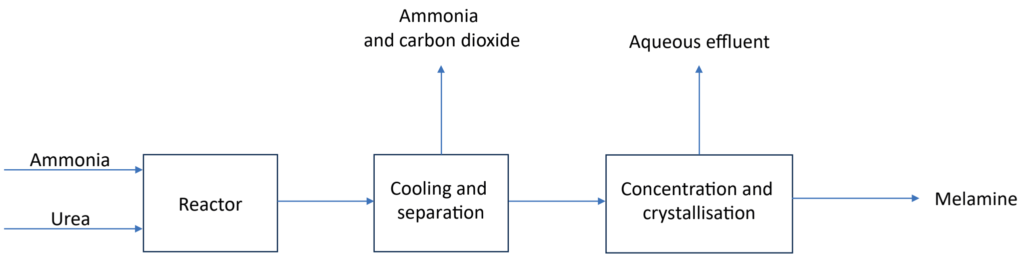
$$6CO(NH_2)_2 \rightarrow 6NH_3 + 3CO_2 + C_3H_6N_6$$

47. *Rodong Sinmun*, '자립경제발전과 인민생활향상에 이바지할 또 하나의 위력한 화학제품생산기지' ['Another Powerful Chemical Product Production Base that Will Contribute to Self-reliant Economic Development and Improvement of People's Lives'], 10 June 2025, archived via the Wayback Machine 25 June 2025, <https://web.archive.org/web/20250625144939/http://www.rodong.rep.kp/ko/index.php?MTJAMjAyNS0wNi0xMC0wNDVAMTVAMUBAMEA2QA==>, accessed 25 June 2025.
48. Richard Heath, 'Aldehyde Polymers: Phenolics and Aminoplastics' in Marianne Gilbert (ed), *Brydson's Plastics Materials*, Eighth edition, (Oxford: Butterworth-Heinemann, 2017), pp. 705–42.

$$6\mathrm{CO}(NH_2)_2 \xrightarrow{NH_3} 3NH_2CN + 3NH_2CO_2NH_4 \rightarrow C_3H_6N_6 + 3NH_2CO_2NH_4$$

A simplified schematic for the process is shown below.

Figure 18: Simplified Schematic for Production of Melamine

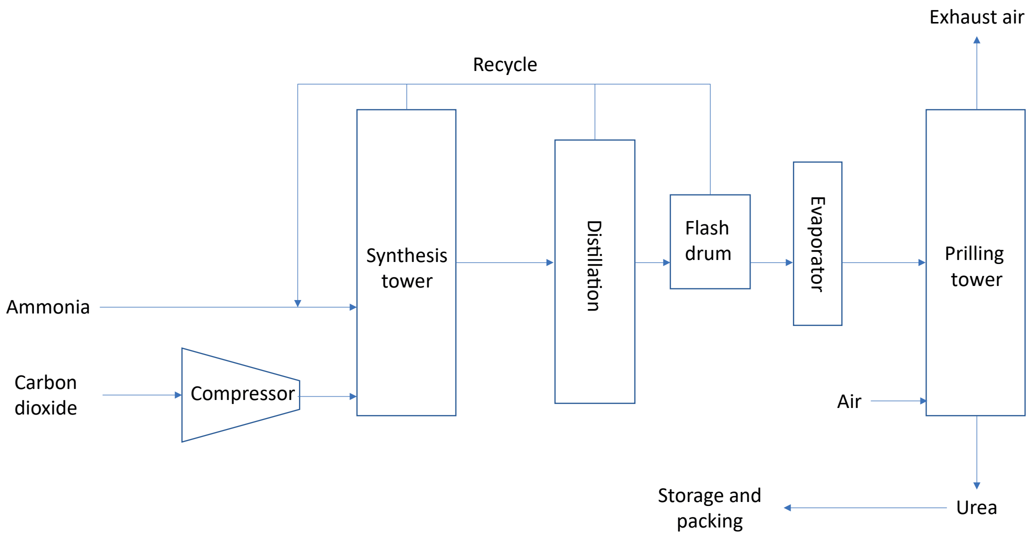


Source: Based on 'How is Melamine Produced?', East Hony, 6 June 2021, <https://www.easthony.com/news/how-is-melamine-produced/>, accessed 22 July 2025; Tjien T Tjioe and Johan T Tinge, 'Integrated Urea – Melamine Process at DSM: Sustainable Product Development' in Jan Harmsen and Joseph B Powell (eds) Sustainable Development in the Process Industries: Cases and Impact *(Hoboken, NJ: John Wiley and Sons, 2010), p. 205.*

Urea Plant

Moving northwards again, the urea plant is located at 39°50'30.8"N 127°37'26.4"E. In short, this plant is used to react ammonia, produced in the ammonia plant, with carbon dioxide, produced in the coal gasification plant, to produce urea and water. The process itself is more involved than this and is shown in the simplified depiction in Figure 19.

Figure 19: Simplified Process Steps to Produce Urea



Source: Based on Jie Ding et al., 'Direct Synthesis of Urea from Carbon Dioxide and Ammonia', Nature Communications (Vol. 14, No. 4586, 2023), *<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10390537/>, accessed 18 July 2025.*

Ammonia is reacted with carbon dioxide in the synthesis tower to form ammonium carbamate. The product stream is fed to a distillation unit, followed by a flash drum to remove unreacted ammonia and carbon dioxide, which are recycled back to the synthesis tower. Most of the water is removed in the evaporator before the final drying and reaction stage which takes place in the prilling towers. In the towers, ammonium carbamate, as a liquid, is fed in the top of the towers, counter current to air fed from the bottom. A reaction takes place which results in the formation of urea and water. The water, as vapour, leaves the towers with the air while the urea forms solid particles (prills) which grow and drop to the bottom of the tower. The solid urea is transferred from the towers to subsequent storage and packing operations.

There are two prilling towers on the Hungnam Fertiliser Complex, as shown in Figure 20.

Figure 20: Urea Production Plant

Source: Maxar Technologies, 3 May 2025. Annotated by the authors.

Liquid Fertiliser Plant

The north-east quadrant of the complex comprises a potential production and manufacturing area, including several high bays, multi and single storey buildings and cooling towers. The proximity of this area to the main entrance of the complex, the ease of access and size of the manufacturing buildings suggests that this could be a final manufacturing area for fertilisers prior to further distribution. Part of this area has been identified as a liquid nutrient fertiliser factory. The liquid fertiliser plant is a new plant located at 39°50’24.0”N 127°37’48.1”E.[49] Construction on this plant started in Q3 of 2019 and continued through most of 2020.

The composition of the fertiliser manufactured on this plant is not clear, but the plant is likely to be a multi-product plant that blends different fertilisers in water to balance the various nutrients required for specific crops in their growing environments.

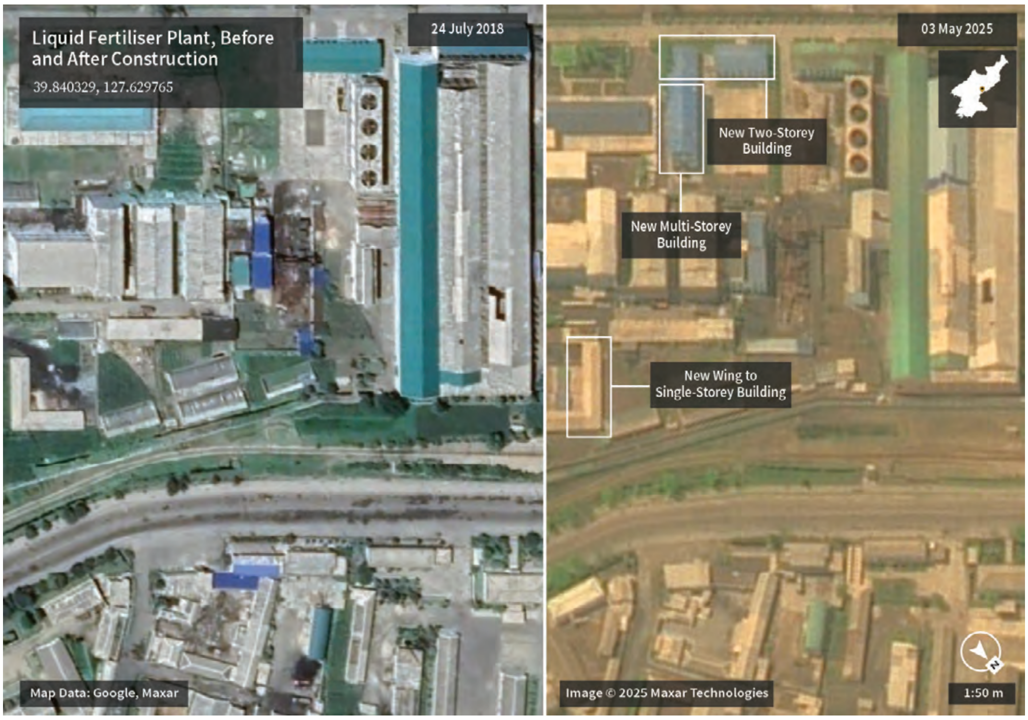
Process equipment is in the building and is likely to include hoppers for the storage of raw materials, mixing vessels and stock tanks for the storage of finished products. Figure 21 shows the broader area around the liquid fertiliser plant, and Figure 22 shows the liquid fertiliser plant before and after the new construction.

Figure 21: Liquid Fertiliser Plant

Source: Maxar Technologies, 3 May 2025. Annotated by the authors.

49. Bermudez Jr and Kim, ‘Hungnam Fertilizer Complex Update: Strategic Modernization for Multi-Purpose Use?’.

Figure 22: Liquid Fertiliser Plant, Before and After Construction



Source: Google Earth (Maxar Technologies) 24 July 2018; Maxar Technologies, 3 May 2025. Annotated by the authors.

Other Manufacturing Locations

It has been difficult to ascertain where the remaining products, identified previously in the site overview, are manufactured. Similarly, there are plant areas which have not been attributed to any product. This section describes areas on the plant site in which manufacturing is likely to be taking place. Following this, processes are described for the identified chemical products which have not already been described in this paper. It is highly likely that these processes will be located in some of the described areas, titled as unknown facilities.

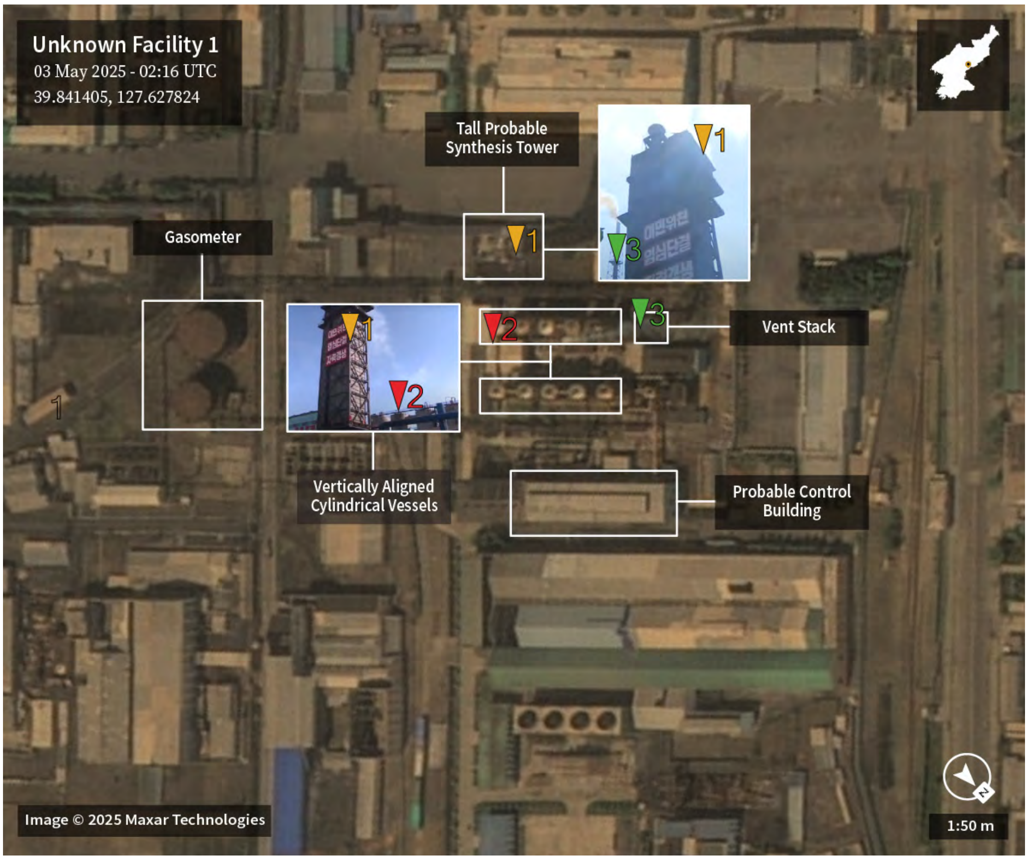
Unknown Facility 1

Sitting between the urea plant and the liquid fertiliser plant, this plant has several interesting features, including:

- A tall tower, probably where the main synthesis reaction takes place (marked 1 in Figure 23).
- Four pairs of vertically-aligned cylindrical vessels, connected by large-bore pipework near the top (marked 2 in Figure 23). This suggests overflow of liquid as some form of separation process.
- A tall vent stack (marked 3 in Figure 23).
- A solids conveyor.

Several multi-level buildings, probably housing manufacturing equipment and a control building, are also located on this plant. There are two gasometers close to the plant. Pipework appears to connect these gasometers with equipment in the plant.

Figure 23: Unknown Facility 1



Sources: Maxar Technologies, 3 May 2025; 우리민족 제일 *[Our People are the Best],* '현지방송 집단적혁신의 불길높이 – 흥남비료련합기업소' *['Local Broadcasting Group Innovation Flames High – Hungnam Fertilizer Complex']. Annotated by the authors.*

Unknown Facility 2

This is a relatively self-contained area partly bordered by walls and buildings. There are several multistorey buildings in the area, some of which are connected by pipework. The buildings probably contain production and processing equipment. There are additionally two large vent stacks and some plant equipment.

Figure 24: Unknown Facility 2

Source: Google Earth (Maxar Technologies), 30 March 2025. Annotated by the authors.

Unknown Facility 3

This facility comprised three main operational buildings and a few other smaller buildings. In late 2020/early 2021, satellite imagery shows a partially damaged roof on the easternmost building in this area. Over the following months the damage got progressively worse, until the end of 2022, when the roof was completely gone. In early 2023, demolition started on the central building; this took around six months to complete. The imagery on the western building also shows a reduction in equipment. Other smaller buildings have also been partially dismantled. It is highly likely that this area is no longer operational. However, the slow rate of demolition is an indicator that equipment may have been relocated and repurposed elsewhere.

Figure 25: Unknown Facility 3

Source: Google Earth (Maxar Technologies) 7 September 2018, 31 March 2021, 17 September 2022 and 30 March 2025..

Unknown Facility 4

This area includes towers and associated equipment, a tall covered structure (which appears on some historical imagery to be surrounded by an off-white material), one large building and several smaller buildings.

Figure 26: Unknown Facility 4

Source: Google Earth (Maxar Technologies), 22 March 2025. Annotated by the authors.

This large building is multi storey and probably used for manufacturing chemicals. Imagery of this large building in August 2012 shows the roof to be intact. By April 2013, imagery appears to show roofing missing on the southeast end, which was repaired by November 2013. At some point between September 2018 and December 2019, this area of the roof appears to have been damaged again, before being repaired again between February and August 2022. Further damage was noted again in September 2024; this was repaired at some point between 22 March 2025 and 3 May 2025, when imagery showed it to be intact again.

From satellite imagery, it has not been possible to determine what material was used to construct and repair the roof. It is conceivable that the same end of the building could have been affected by external factors, such as weather, multiple times in a relatively brief period. However, the damage may well have been caused by some sort of recurring process-related issue, such as release of corrosive chemicals or recurring over-pressure situations.

Figure 27: Condition of Roof

Source: Google Earth (Maxar Technologies), 9 August 2012, 13 May 2013, 24 July 2018, 31 March 2021, 2 June 2023 and 22 March 2025.

From available imagery, an additional open but roofed structure was constructed at some point in 2017, with imagery from September 2024 showing the roof having been expanded.

Figure 28: Tall Open Covered Structure

Source: Google Earth (Maxar Technologies), 3 June 2016, 7 September 2018 and 22 March 2025.

Remainder of Site

The rest of the site is similarly split into distinct areas. Several of these areas have large multistorey structures, indicating the likelihood of some form of manufacturing taking place inside them. Others appear to be no more than small single-storey buildings. These areas are likely to include amenities, laboratories, maintenance and fabrication buildings, offices and so on. There is also an additional small electrical substation located at 39°50'24.3"N 127°38'02.7"E.

The following sections describe the various processes believed to be operating on the site, but for which specific areas have not been identified.

Sulfuric Acid Production

Sulfuric acid is produced in a process involving several consecutive steps:

- The production of sulfur dioxide.
- The production of sulfur trioxide.
- The dissolution of sulfur trioxide in sulfuric acid to produce oleum.
- The addition of water to oleum to produce sulfuric acid.

Given that hydrogen sulfide (H_2S) is obtained from the desulfurisation of gases in the coal gasification plant, it is logical to assume that it would be used for at least part of the sulfur component of sulfuric acid. However, depending on process conditions, the burning of H_2S in air / oxygen can produce water and sulfur or sulfur dioxide, as indicated in the two equations below.

$$2H_2S + O_2 \rightarrow 2H_2O + 2S$$

$$2H_2S + 3O_2 \rightarrow 2H_2O + 2SO_2$$

Any sulfur produced could either be subsequently burnt in air to produce sulfur dioxide or separated to produce sulfur as a plant output:

$$S + O_2 \rightarrow SO_2$$

The resultant stream is dried before undergoing a catalysed reaction with oxygen (in air) to form sulfur trioxide. This is dissolved in sulfuric acid to produce oleum, to which water is added, producing sulfuric acid:

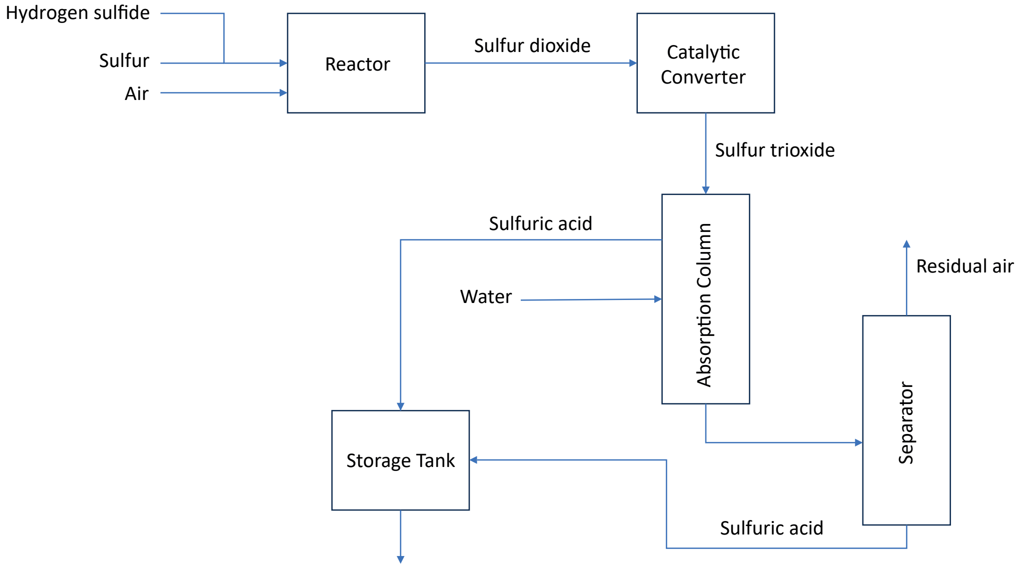
$$2SO_2 + O_2 \rightarrow 2\ SO_3$$

$$SO_3 + H_2SO_4 \rightarrow H_2S_2O_7$$

$$H_2S_2O_7 + H_2O \rightarrow 2\ H_2SO_4$$

A simplified schematic for the process is shown in Figure 29.

Figure 29: Simplified Process Steps in a Sulfuric Acid Plant

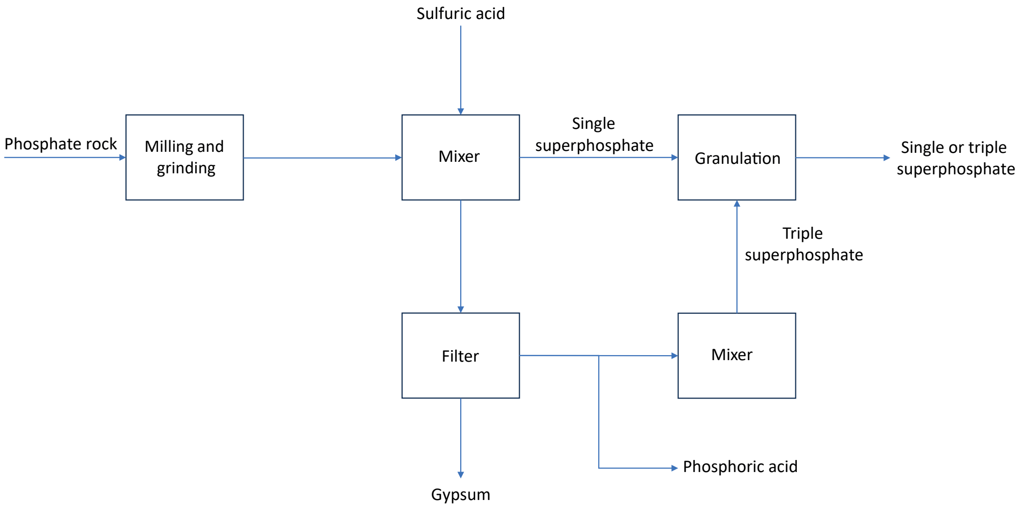


Source: Based on Thlama Mperiju et al., 'Optimized Production of High Purity Sulphuric Acid via Contact Process,' Logistic and Operation Management Research *(Vol. 2, No. 1, 2023), p. 3.*

Phosphoric Acid and Superphosphate Production

Both phosphoric acid and single superphosphate are produced from the reaction of ground phosphate rock and sulfuric acid. However, these processes diverge depending on the ratio of sulfuric acid to phosphate rock, as well as the separation processes following the reaction; phosphoric acid can be used to make triple superphosphate.

Figure 30: Simplified Process Steps in a Phosphoric Acid/Superphosphate Plant



Source: Based on Valco, 'Manufacturing Process of Phosphate Fertilizers, <https://www.valcogroup-valves.com/faq-2/phosphate-fertilizers-manufacturing-process-of-phosphate-fertilizers/>, accessed 18 July 2025*; New Zealand Institute of Chemistry, 'The Manufacture of Sulfuric Acid and Superphosphate,' <https://www.nzic.org.nz/unsecure_files/book/1B.pdf>, accessed 18 July 2025.*

Ammonium Phosphate Plant

Phosphoric acid can be reacted with anhydrous ammonia to make ammonium phosphate. Because of the simplicity of this additional step, it would be reasonable to assume that this product could be manufactured in the same plant as phosphoric acid and superphosphate.

Ammonium Nitrate Facility

The reaction of ammonia and nitric acid produces ammonium nitrate, initially as a solution. This may be shipped out as a solution or alternatively dried and shipped out as solids.

As this process requires both ammonia and nitric acid, it is quite conceivable that it is co-located with the nitric acid plant. Similarly, as a solution, it would be reasonable to assume this product could be manufactured in the liquid fertiliser plant.

Although it is predominantly used as a nitrogen-rich fertiliser, ammonium nitrate can also be used in the manufacture of explosives.

Gas Storage Tank Farm

There is a tank farm located at 39°50'21.9"N 127°37'19.1"E. Satellite imagery shows features of these storage tanks that are consistent with gasometers, where gas is stored at ambient conditions. These gases probably include syngas, hydrogen, hydrogen sulfide and other high-volume gas feedstocks for the complex.

There is a major explosives storage facility less than two miles away from the complex, probably associated with this site and/or the Vinalon complex. It includes a manufacturing compound and a bulk liquid storage facility.

There are two air defence sites located immediately to the east of the facility (one is annotated as a cemetery on Google Earth maps) – which also probably cover the Vinalon complex and the adjacent, extensive explosives storage area – and a third air defence site on the peninsula to the southeast of the facility, adjacent to a military naval base.

Electricity is probably generated internally, and there are two electricity substations within the complex. The supply of water cannot be directly ascertained on available imagery, but there are two water purification plants less than two miles away, fed by the adjacent river, which is likely the source. There is also a closed system of canals within the facility, probably used to both distribute unpurified water around the complex and discharge wastewater directly into the sea at the eastern end of the port facility. There are also two water settling ponds within the complex.

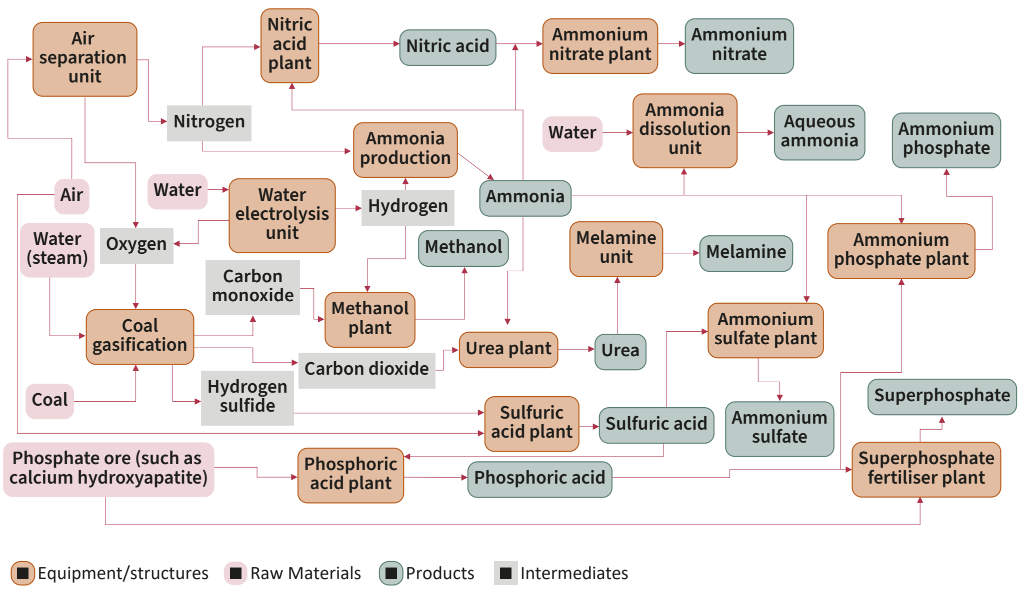
The complex is partially walled, although there are at least two major road access points that do not appear to be physically controlled. Several functional areas within the complex are separately secured.

In some areas, it has been possible to identify plant equipment, which clearly indicates that those areas are being used for chemical manufacture. In other areas, there are more subtle indicators to manufacturing taking place. Other areas comprise buildings which may be used for processing, production, storage, maintenance, amenities, laboratories, control rooms and so on.

Overall Complex Process Flow

Figure 31 demonstrates how the processes described above might fit together within the Hungnam Fertiliser Complex, and demonstrates a well-integrated plant site. Whereas the authors have largely named the different areas of the site as separate plants, it is very possible that manufacture of materials with similar feedstocks and reaction conditions may take place within multipurpose production lines.

Figure 31: Possible Overall Process Flow within the Hungnam Fertiliser Complex



Source: The Project Anthracite Team, based on content in this report.

Theoretical Pathways to CWAs

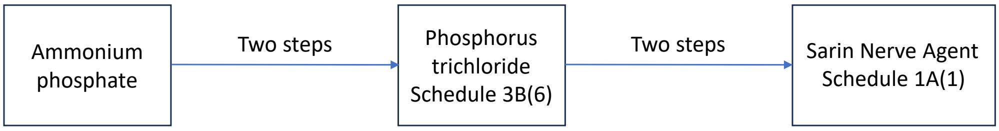
Project Anthracite recently released a report, 'Raw Materials for Potential Chemical Warfare Agents', which provides a basic background and reference document for the chemistry outlined in this section of this paper.[50]

Retrosynthetic analysis[51] of the Hungnam feedstocks highlights that some of the chemicals utilised on site could potentially be exploited for CWA production (see Table 1). For example, phosphorus oxychloride and phosphorus trichloride can theoretically be prepared in two or three synthetic steps respectively from the ammonium phosphate produced at Hungnam Fertiliser Complex. Listed as schedule 3 materials under the CWC, both phosphorus oxychloride (CWC Schedule 3B(5) material)[52] and phosphorus trichloride (CWC Schedule 3B(6) material)[53] could be further utilised to produce CWAs such as G series (for instance, sarin, soman and tabun) and V series (such as VX) nerve agents. For instance, sarin could be produced from phosphorus trichloride in as little as two synthetic steps, with the right available materials (see Figure 32). The more

50. The Project Anthracite Team, 'Raw Materials for Potential Chemical Warfare Agents', RUSI, 16 July 2025, <https://www.rusi.org/explore-our-research/publications/special-resources/raw-materials-potential-chemical-warfare-agents-technical-assessment-1>, accessed 23 July 2025.
51. Stuart Warren, *Designing Organic Syntheses: A Programmed Introduction to the Synthon Approach* (Hoboken, NJ: Wiley, 1978).
52. OPCW, 'Annex on Chemicals: Schedule 3', < https://www.opcw.org/chemical-weapons-convention/annexes/annex-chemicals/schedule-3>, accessed 23 July 2025.
53. *Ibid*.

toxic nerve agent, VX, would require a five-step process, with an initial step involving phosphorus trichloride.

Figure 32: Theoretical G-Series Nerve Agent Production Pathway from Hungnam Feedstock



Source: The Project Anthracite Team.

Table 1 identifies selected Hungnam feedstocks that could be used as CWA raw materials or for CWA production, noting the schedule allocated to each chemical.

Table 1: Selected Hungnam Chemicals that Could be Utilised for CWA Production

Chemical Manufactured on Hungnam Fertiliser Complex	**Scheduled Chemical Precursor** **(Number of Synthetic Steps from Chemical Manufactured on Hungnam Fertiliser Complex)**	**CWA** **(Number of Synthetic Steps from CWA Starting Material)**
Ammonium phosphate	Phosphorus oxychloride – 3B(5) (two steps)	Tabun (two steps)
Super phosphate fertiliser	Phosphorus trichloride – 3B(6) (two steps)	Sarin (two steps), soman (two steps), tabun (three steps), VX (five steps)
Ammonia	N/A	Tabun (two steps)
	N,N-Diisopropylaminoethanol – 2B(11) (two steps)	VX (two to three steps)
	N-Ethyldiethanolamine – 3B(15) (two steps)	Nitrogen mustard (one step)
Hydrogen sulfide	Thiodiglycol – 2B(13) (one step)	Sulfur mustard (one step)
	Sulfur monochloride – 3B(12) (2 steps)	
	Sulfur dichloride 3B(13) (two steps)	
	None	

Source: The Project Anthracite Team.

It is worth noting, however, that although ammonium phosphate and super phosphate fertiliser can be used to produce phosphorus oxychloride $(POCL_3)$ and phosphorus trichloride (PCl_3) respectively, the routes to $POCl_3$ and PCl_3 would be simpler when produced more directly from apatite.

Additionally, methanol is produced on site. Methanol is a building block chemical which can be utilised to build basic organic chemicals including raw materials for Schedule 1 chemicals, such as trimethyl phosphite (Schedule 3B(8)) and methyl diethanolamine (Schedule 3B(16)). These raw materials can be used in subsequent steps to make sarin, soman, tabun, VX, nitrogen mustard HN2 and methylphosphonyl difluoride (DF). Due to this broad range of chemicals and their being produced in the early synthetic stages, methanol has not been included in the table above.

Relevance to the CWC

The analysis in this section is based on the findings from open source information and do not necessarily reflect the real situation.

No scheduled chemicals have been identified as being produced during the manufacture of fertilisers on Hungnam Fertiliser Complex. On this basis, the site would not be declarable under parts VI, VII and VIII of the Verification Annex of the CWC (VA).[54]

According to paragraph 4 of part I of the VA, methanol, melamine and urea would be classed as unscheduled Discrete Organic Chemicals (DOCs).[55] From satellite imagery, methanol, melamine and urea all appear to be produced in relatively self-contained areas. As such, they are likely to be considered as separate plants, giving three plants that produce DOCs.

The OPCW Declarations Handbook (DH) indicates that product group codes 519 (‘methanol, ethanol, urea, formaldehyde, ethyl tert-butyl ether (ETBE), methyl tert-butyl ether (MTBE), surfactants based on sulfonic acids and fatty acid salts’) and product group code 514 (‘nitrogen-function compounds, except urea’) would be the main activities of this plant site, which would be declarable under Part IX of the VA.[56]

In terms of production range, the size of the equipment related to urea production is large scale, as would be expected with the production of urea. This would certainly show production capability of urea alone as exceeding 10,000 tonnes per year (see Appendix 7 of the DH). In addition, in 2003, the Food and Agriculture Organisation of the United Nations (FAO) issued a report which gave the production capacity of urea at Hungnam Fertiliser Complex as 170 kilo tonnes,[57] which also exceeds 10,000 tonnes per year. Although this information from the FAO is over 20 years old, the North Korean reliance on food means that this capacity is more likely to have increased than

54. OPCW, ‘Verification Annex’, <https://www.opcw.org/chemical-weapons-convention/annexes/verification-annex/part-i-definitions>, accessed 18 July 2025.
55. *Ibid.*
56. OPCW, ‘Declarations Handbook 2013, Revised Version 3, 1 January 2022’ <https://www.opcw.org/sites/default/files/documents/2021/12/Declarations%20Handbook%202013%20Revised%20Version%203_0.pdf>, accessed 9 June 2025, p. 123, p. 321–322.
57. Food and Agriculture Organisation of the United Nations, ‘Fertilizer Use by Crop in the Democratic People’s Republic of Korea’, 2003, p. 8, <https://openknowledge.fao.org/server/api/core/bitstreams/2e2a338c-27eb-4237-802a-9e9619967b2f/content>, accessed 22 July 2025.

decreased over this time period. Neither the size of the equipment nor the production capacity actually define the amount of production, as capacity does not account for shutdowns, low production rates and so on. So while the declared production range is likely to be over 10,000 tonnes per year, the actual production range would depend on actual output in a given year.

Among the identified chemicals, there are no DOCs containing the elements phosphorus, sulfur or fluorine (PSF-chemicals), so the number of plants producing PSF-chemicals is nil.

Conclusions

Fertiliser is crucial to food production in North Korea. Over recent years, the Hungnam Fertiliser Complex has undergone several changes and modifications, underlying this key role. All the information analysed in relation to this complex indicates that it is a large, well-integrated plant site, used for the manufacture of fertilisers from basic raw materials such as coal, air, water/steam and rock. Equipment identified on satellite imagery is consistent with large-scale processes, which is what would be expected in the production of fertilisers. The only outlier is the production of methanol, which is not used in the manufacture of fertilisers on the site. It is, however, very logical to produce methanol on the site, given that all the basic raw materials are present.

The site is laid out in a logical manner, where processes progress from coal, air and water/steam in the southwestern part of the plant site to urea in the northwestern part. Other plants are located adjacent to these, while buildings which appear to have more of a support function are located to the east of the site. There are no areas which appear to be inconsistent with this general appearance, and therefore no areas seem likely to be used for anything other than processes related to the production of fertiliser.

While it is not possible to see what takes place inside a building, none of the available information supported the premise that the Hungnam Fertiliser Complex is being used to produce CW. However, several chemicals were identified, which are legitimately produced as fertilisers, that could be used in downstream processes to produce scheduled chemicals.

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This report was authored by members of the RUSI Project Anthracite Team, who provide varying levels of input to the reports produced by the project.[58] The team includes the following:

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58. RUSI, 'Project Anthracite: Assessing the Chemical Weapons Capability of the DPRK'.

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