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Remote Assessment of North Korea's Chemical Weapons Feasible or Not?

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Contents

Executive Summary	v
Introduction	1
Background	3
Methodology for the Feasibility Study	5
I. Case Study: The Namhung Youth Chemical Complex	9
Chemical Activity at the Namhung Youth Chemical Complex	14
A Chemical Weapons Risk?	19
Signatures and Remote Sensing	24
Tentative Conclusions and Pathways for Further Research	31
About the Authors	33

Executive Summary

THE INTERNATIONAL COMMUNITY widely perceives North Korea to possess an offensive chemical weapons (CW) programme. However, detailed understanding and analytical assessment of its status, scope and scale is lacking, especially in the public domain. Although North Korea is notorious for being a hard target to assess, there are an increasing number of open source and commercially available tools – such as higher-resolution satellite imagery and remote sensing technologies – that researchers have used to gather data to inform assessments of North Korea’s nuclear weapons activities. However, the applicability and usefulness of these tools being applied to support critical assessment of a CW programme remains underexplored.

This feasibility study investigates how open source research and remote sensing technologies could be used to assess North Korea’s CW capability. The authors have taken a case study approach, looking specifically at the activities of the Namhung Youth Chemical Complex in Anju, North Korea. The paper maps out possible chemical processes at the complex, identifies possible CW risk, explores what signatures these activities may have and assesses how remote sensing could support further analysis.

The authors conclude that the Namhung Youth Chemical Complex is not a site used purely for CW production, but does likely retain activities relevant for CW. They assess that for such an approach to have the most value, the method would need to be replicated across North Korea’s chemical industry and analysis should consider CW production as a network and not on a site-by-site basis. The paper finds that while remote sensing tools will not be a silver bullet in assessing the status, scope and scale of North Korea’s CW programme, they can be used to refine hypotheses about North Korea’s CW capability.

Introduction

NORTH KOREA'S WMD capabilities have long been a concern for the international community. Although its nuclear programme has been the most prominent capability of concern, North Korea is also suspected to possess a chemical weapons (CW) programme. Some governments have highlighted concerns over this,¹ and the UN Security Council has referenced North Korea's CW in resolutions.² Yet, this capability has faced significantly less attention and is much less understood.

The focus on North Korea's nuclear proliferation has been driven by obvious and explicit activities, such as nuclear tests, which have been ongoing since the 2000s. These nuclear tests have been detected by international and national monitoring systems, and the country has declared itself a nuclear power. It has shared images in state media of its technical developments and at times allowed international personnel to visit the Yongbyon Nuclear Complex. The visibility of the nuclear programme to open source researchers has been significantly bolstered in recent years by advances in commercially available remote sensing technologies and higher-resolution satellite imagery. These tools have allowed research regarding North Korea's nuclear proliferation to become more accessible for those outside of the governments that possess advanced remote sensing assets. Using high-resolution optical imagery, synthetic aperture radar³ and thermal infrared imagery,⁴ together with data gathered from other open source research, researchers can make analytical assessments about the operational status of key nuclear facilities without relying solely on on-the-ground access⁵ or second-hand reporting of government assessments that may be politically influenced and have opaque methodologies.

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1. See, for example, US Office of the Secretary of Defense, 'Military and Security Developments Involving the Democratic People's Republic of Korea', 2017; Ministry of National Defense of South Korea (MND), 'Defense White Paper', 2016, <https://www.mnd.go.kr/user/mndEN/upload/pblicitn/PBLICTNEBOOK_201705180357180050.pdf>, accessed 18 February 2022.
 2. See UN Security Council Resolution (UNSCR) 2270 (2016).
 3. See, for example, Jeffrey Lewis, 'SAR Image of Punggye-ri', *Arms Control Wonk*, 13 September 2017.
 4. See, for example, Joseph Bermudez et al., 'Thermal Imagery Indicates Activity at Yongbyon Nuclear Reprocessing Facilities', *Beyond Parallel*, 15 April 2021.
 5. In partnership with the Verification Research, Training and Information Centre (VERTIC) and the Center for Nonproliferation Studies (CNS), RUSI is engaged in a multi-year effort that employs novel methodologies and uses advances in remote sensing technologies to assess and model various scenarios for North Korea's nuclear weapons programme. For more information on this project, see RUSI, 'North Korea's Weapons of Mass Destruction Capabilities', <<https://rusi.org/explore-our-research/projects/north-korea%E2%80%99s-weapons-of-mass-destruction-capabilities>>, accessed 28 February 2022. For an example of this work, see Dave Schmerler, 'A Satellite Imagery Review of the Pyongsan Uranium Mill', *Arms Control Wonk*, 1 July 2020.

However, these tools and techniques are seldom applied to assessing CW capabilities within the country, and indeed elsewhere. Although optical imagery has been used in the context of the Syrian conflict as part of efforts to investigate the alleged use of chemical warfare agents,⁶ there has been less focus on using remote sensing and open source research to make analytical judgements about CW programmes more broadly. One reason for this comes from questions over the effectiveness of using remote sensing to make analytical assessments about CW capabilities: the processes and equipment used in chemical warfare agent production are often dual use, making it difficult to assess intent for civil or military purposes. Furthermore, chemical agent production processes are often housed in generic, industrial-style buildings – from the outside, it is difficult to know what exactly is taking place within.

The authors have begun to explore the question: to what extent is open source research and remote sensing useful in informing assessments about North Korea's CW capability?⁷ Using a case study approach, in collaboration with the Defence Science and Technology Laboratory (Dstl), initial research suggests that, contrary to first assumptions, there is value in using these tools in the context of North Korea's CW capability.

This feasibility study has been exploratory. It is not a definitive assessment of a CW programme in North Korea. Nor is it a comprehensive effort to catalogue and assess all activities in North Korea that are indicative of the production of chemical warfare agents. Instead, the contribution of this work is to explore the utility of new research methods and begin to assess the extent to which they can help the understanding and analysis of CW capabilities in North Korea.

Open source research and remote sensing tools are also not a silver bullet and must be understood as a way to gather additional data for analysis. While they do not offer conclusive insights, they can support the identification and refinement of hypotheses regarding activities that could be relevant for the production of chemical warfare agents. Although the authors have reached some positive conclusions about the applicability of the methodology, this work is not definitive. The scope of this project has not allowed the authors to fully implement and test remote sensing tools in this context.

This paper covers the authors' initial work and tentative findings. It first discusses the scope of the study, why it is important and its purpose. It then outlines the research methodology. The rest of the paper lays out the case study and concludes with initial assessments on the feasibility and utility of using remote sensing and open source research to assess North Korea's CW capability.

6. Eliot Higgins, 'The Open Source Hunt for Syria's Favourite Sarin Bomb', *Bellingcat*, 21 April 2020.

7. Defined in this paper as the presence of chemicals and processes that are able to support an offensive chemical weapons (CW) programme.

Background

Remote sensing refers to the use of sensors on satellites and aircraft to gather data about on-the-ground activities. Satellite imagery and remote sensing tools have long been used by governments to gather data and information about areas and activities not always accessible on the ground. During the Cold War, such capability was limited to the US and the Soviet Union.⁸ However, as technologies have advanced and costs decreased, remote sensing capabilities on satellites have become commercially viable and thus available to those outside well-resourced governments.⁹ This has allowed many non-governmental organisations (NGOs) to use these tools and technologies for a variety of purposes.

In the field of arms control and non-proliferation, remote sensing has been used for the monitoring and analysis of North Korea's nuclear weapons programme.¹⁰ Optical imagery has shown construction and development at key locations,¹¹ as well as evidence of activity.¹² For example, thermal infrared imagery has indicated when certain buildings and facilities have been active,¹³ and synthetic aperture radar (SAR) imagery has been used to detect subsidence in the mountain which housed North Korea's sixth underground nuclear test, which was used to support calculations of estimated yield.¹⁴

However, the application of open source research and remote sensing tools in the context of assessing North Korea's CW capability has been sparse. Declassified CIA reports have noted the use of overhead imagery in monitoring chemical industrial sites,¹⁵ but do not publicly make assessments about CW efforts or give details of the imagery analysis. A recent UN Institute for Disarmament Research (UNIDIR) study has highlighted ways in which remote sensing might

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8. Melissa Hanham and Jeffrey Lewis, 'Remote Sensing Analysis for Arms Control and Disarmament Verification', Federation of American Scientists, 2015.
 9. James Revill and John Borrie (eds), 'Science and Technology for Monitoring and Investigation of WMD Compliance', UN Institute for Disarmament Research (UNIDIR), 2020.
 10. Work by David Albright in the early 2000s broke new ground in using commercially available satellite imagery to analyse North Korea's proliferation activities. See David Albright and Kevin O'Neill, *Solving the North Korean Nuclear Puzzle* (Washington, DC: ISIS Press, 2000). For examples of more recent efforts to use remote sensing and satellite imagery, see Melissa Hanham, 'Using Open-Source Intelligence to Verify a Future Agreement with North Korea', Carnegie Endowment for International Peace, 27 July 2021.
 11. Olli Heinonen, 'Development of the Yongbyon Uranium Enrichment Plant Between 2009 and 2021', *38 North*, 16 July 2021.
 12. Schmerler, 'A Satellite Imagery Review of the Pyongsan Uranium Mill'.
 13. Bermudez et al., 'Thermal Imagery Indicates Activity at Yongbyong Nuclear Reprocessing Facilities'.
 14. Lewis, 'SAR Image of Punggye-ri'.
 15. See, for example, CIA, 'Basic Imagery Interpretation Report: Hungnam Nitrogen Fertilizer Plant, Hungnam, North Korea', June 1969; CIA, 'Basic Imagery Interpretation Report: Nampo Phosphate Fertilizer Plant, Nampo, North Korea', March 1971.

be applied to the monitoring of potential CW activities.¹⁶ This paper notes the potential role technologies such as hyperspectral or infrared imagery could play in observing 'signs of a chemical reaction such as colour change, oxidation, or unusual or unexpected environmental stress'.¹⁷ However, it did not explore how this might be applied in a specific context, nor the value this data would have in assessing a potential offensive CW programme. Other work has used satellite imagery to support analysis about activities taking place at North Korea's chemical sites, and what this could mean for the existence of an offensive CW programme,¹⁸ but this analysis has largely stopped at the point of concluding that an expansion of activities could result in additional capability and capacity for CW production. It has not gone as far as to explore other remote sensing tools for specific chemical assessments.

Exploring ways to better assess North Korea's potential CW capability is an important endeavour.¹⁹ North Korea is not party to the Chemical Weapons Convention (CWC), the international treaty that prohibits the development, acquisition and stockpiling of chemical weapons. Furthermore, governments and non-governmental analysts have assessed that North Korea likely possesses chemical weapons.²⁰ However, reliable and interrogable information regarding the nature, scale and scope of a North Korean CW programme is extremely sparse. The regime disputes these claims.²¹

Considering how the international community can better understand North Korea's CW capability is important for three key reasons:

1. Very little is known about North Korea's potential CW capability, yet the bar for use in a conflict is likely to be lower than that for nuclear weapons. Better understanding the limits and plausible nature of capabilities could contribute to improved planning, especially civil resilience and protection.
2. Having an improved and more rigorous assessment of capabilities can aid contingency planning for scenarios of domestic instability or regime collapse. Such scenarios might

16. Borrett et al., 'Science and Technology for WMD Compliance Monitoring and Investigations'.

17. *Ibid.*

18. Joseph S Bermudez Jr and Dana Kim, 'Hungnam Fertilizer Complex Update: Strategic Modernization for Multi-Purpose Use?', *Beyond Parallel*, 8 September 2020; Joseph S Bermudez Jr, 'North Korea's Namhung Youth Chemical Complex: Seven Years of Construction Pays Off', *38 North*, 10 April 2014.

19. Cristina Varriale, 'North Korea's Other Weapons of Mass Destruction', *Arms Control Today* (Vol. 48, No. 7, September 2018), pp. 6–10.

20. See, for example, MND, 'Defense White Paper', 2018; US Office of the Secretary of Defense, 'Military and Security Developments Involving the Democratic People's Republic of Korea'; Patrick R Terrell, 'North Korean Collapse: Weapons of Mass Destruction Use and Proliferation Challenges', North Korea Instability Project, June 2017.

21. *KCNA*, 'U.S. Anti-DPRK Propaganda Slammed', 2 March 2018. It is not possible to provide direct weblinks to North Korean outlets. However, the authors have maintained a record of all references from North Korean sources.

warrant the international community working to secure and eventually dismantle WMD capabilities.

3. CW have been used in recent years. For example, VX was used in the assassination of Kim Jong Nam in Malaysia;²² Novichok agents were used in the Salisbury attacks²³ and against Russian dissident Alexei Navalny;²⁴ and chlorine, sarin and mustard gas have been used in the Syrian conflict.²⁵ North Korea is widely reckoned to have been involved in the Kim Jong Nam assassination.²⁶ The regime in Pyongyang also maintains a longstanding relationship with the Assad regime. This relationship has included broad military cooperation, and possible CW cooperation.²⁷

Methodology for the Feasibility Study

This paper had a three-step research process:

1. Gathering data and information to build a case study which could be used to test the viability of open source research and remote sensing.
2. Analysis and assessment of the chemical activities and, based on this, considering whether the chemical activities identified at the site have any relevance for CW production.

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22. US State Department, 'Imposition of Chemical and Biological Weapons Control and Warfare Elimination Act Sanctions on North Korea', press statement, 6 March 2018, <<https://2017-2021.state.gov/imposition-of-chemical-and-biological-weapons-control-and-warfare-elimination-act-sanctions-on-north-korea/index.html>>, accessed 7 December 2021.
 23. Karen Pierce, 'Evidence of Russia's Involvement in Salisbury Attack', speech, last updated 7 September 2018, <<https://www.gov.uk/government/speeches/you-dont-recruit-an-arsonist-to-put-out-a-fire-you-especially-dont-do-that-when-the-fire-is-one-they-caused>>, accessed 7 December 2021.
 24. Ministry of Foreign Affairs of France, 'Joint Statement by the Foreign Ministers of France and Germany – Alexei Navalny', 7 October 2020, <<https://www.diplomatie.gouv.fr/en/country-files/russia/news/article/joint-statement-by-the-foreign-ministers-of-france-and-germany-alexei-navalny>>, accessed 7 December 2021.
 25. Organisation for the Prohibition of Chemical Weapons (OPCW), 'OPCW Confirms Use of Sarin and Chlorine in Ltamenah, Syria, on 24 and 25 March 2017', 13 June 2018, <<https://www.opcw.org/media-centre/news/2018/06/opcw-confirms-use-sarin-and-chlorine-ltamenah-syria-24-and-25-march-2017>>, accessed 7 December 2021; UNSC, 'Seventh Report of the Organisation for the Prohibition of Chemical Weapons-United Nations Joint Investigative Mechanism', <https://www.un.org/ga/search/view_doc.asp?symbol=S/2017/904>, accessed 14 December 2021.
 26. 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', 14 March 2018, <https://www.opcw.org/sites/default/files/documents/EC/87/en/ec87nat14_e_.pdf>, accessed 14 December 2021.
 27. Samuel Ramani, 'The North Korean-Syrian Partnership: Bright Prospects Ahead', *38 North*, 23 March 2021.

3. Analysis of the overlap between the signatures of chemical activity and CW specifics at the case study site, and examining how remote sensing might be able to support further analysis and assessment of CW capability.

A case study approach was used to help bound the feasibility study. The study focused on a single industrial facility previously thought to be associated with a CW programme and explored the utility of open source research and remote sensing for its specific capability and activity. The study focused on a large-scale industrial site for two reasons. First, industrial sites are more easily identifiable due to their size and scale. Second, there are many chemical industrial sites in North Korea that have in the past been thought to be linked to or associated with CW production.²⁸

The alternative approach was to identify relevant processes and capabilities needed to produce all Schedule 1 chemicals under the CWC,²⁹ the class of chemicals that is deemed to have no civil purpose and includes known CW agents. As there are multiple production routes for these chemicals, this approach would have been much more complicated as it would have required assessing them all, then determining whether the associated processes and capabilities were present anywhere in North Korea and how they might be assessed using remote sensing. This was considered out of the scope of this feasibility study. It is possible that future studies could consider different production routes, with a specific focus on small-scale activities, as well as weaponisation and delivery mechanisms.

Prior to choosing the subject of the case study, the authors gathered information from governmental and non-governmental documents regarding North Korea's chemical industry. This literature review primarily drew on South Korean and US governmental assessments of the chemical industry in North Korea (including historical, declassified documents) as well as other think tank and academic reports that identified specific facilities believed to be linked to North Korea's CW programme. This resulted in a list of over 20 sites that could be considered for this work.

From this list of chemical sites, the Namhung Youth Chemical Complex was selected for the case study because: it is still an active and core chemical complex in North Korea; it has been linked to a CW programme in the past by governments, NGO assessments and defector testimonies;³⁰ and these two previous factors meant that there were historic and contemporary secondary and primary sources with data about the site.

To gather data on the Namhung complex, the authors drew on numerous governmental and non-governmental sources, including: US, South Korean and Japanese defence white papers and governmental reports; declassified documents from the CIA archives; other think tank and

28. See, for example, MND, 'Defense White Paper', 1990; MND, 'Defense White Paper', 1991–92; MND, 'Defense White Paper', 1992–93.

29. See OPCW, 'Annex on Chemicals – Schedule 1', <<https://www.opcw.org/chemical-weapons-convention/annexes/annex-chemicals/schedule-1>>, accessed 11 February 2022.

30. These three categories of sources are discussed in the case study section.

academic research on the complex; and North Korea state media reporting – primarily *Korean Central News Agency (KCNA)* and the *Pyongyang Times* – including videos from YouTube channels linked to North Korea. To build a more detailed picture of the production processes taking place at the complex – either currently or in the past – information on chemicals, equipment and production capacities was compiled from a number of media sources, technical reports and videos. This information was considered in the context of industrial production, allowing raw materials, intermediates and final products to be identified, and probable linkages between the production processes to be established. The resultant technical information was examined further to determine whether the chemicals and equipment employed in these reported processes were relevant in a CW context. By reviewing these primary and secondary sources, the authors were able to build a picture of chemical activities linked to the Namhung complex.

The second way in which data was gathered for the feasibility study was through a series of three workshops with subject matter experts, which took place in September 2019, November 2020 and June 2021. All were held on a not-for-attribution basis.

The first workshop, held in London, convened several experts from international organisations and NGOs, as well as current and former government representatives. Participants had a range of expertise including on CW issues and North Korea. The purpose of this workshop was to explore the fundamental and common features of CW programmes and to discuss public assessments of North Korea's CW capability. Including a diverse pool of expertise and perspectives allowed participants to challenge assumptions and critically discuss the differences between the typical features of an offensive CW programme and atypical features that might occur in the North Korean context. These discussions enabled the authors to begin to develop a list of features and activities related to CW development that could be considered in the context of the case study, and helped to refine the focus of this feasibility study. These discussions reinforced a distinction between two broad production routes. Simplistically: CW programmes can be large in scale and underpinned by industrial-scale facilities, and chemical warfare agents can also be produced on a small scale in laboratories. This workshop helped to confirm the authors' decision to focus on large-scale production, with workshop participants agreeing that larger infrastructure affords more opportunities to test the applicability of remote assessment.

In November 2020, a second workshop brought together North Korea experts as well as those with expertise in CW issues and remote sensing. The purpose of this workshop was to begin exploring signatures of chemical processes and CW programmes in the context of remote sensing tools. This workshop allowed the authors to explore where signatures of chemical activity and remote sensing capabilities might overlap.

A third workshop was held in June 2021. This meeting brought together remote sensing experts with chemical plant operators and engineers. Learnings from the previous workshop highlighted that remote sensing assessments, open source or otherwise, are always strengthened with the inclusion of expertise relevant to on-the-ground activities. This workshop focused solely on activities at the Namhung Youth Chemical Complex.

Limitations

There are, of course, several limitations with this case study approach. First, it is not all encompassing. CW programmes and the inputs required to establish and maintain them are varied; not only is the technical capability required, but so too are personnel with the correct scientific and engineering knowledge and the ability to weaponise, deliver and maintain CW. This study only considers the applicability of remote sensing and open source research in the context of large, industrial production facilities. The authors have not considered the acquisition of precursors from outside the country via proliferation networks or the small-scale production routes that could take place in university or other small-scale laboratories, for example. Other factors such as tacit knowledge or university/academic research activities undertaken in North Korea, or indeed by North Koreans outside the country, have also not been explored. Furthermore, the focus is on chemical warfare agent production and not delivery systems or doctrine. Consideration of these activities would give a more complete picture of CW capability in North Korea.

Second, and related, this study does not look at the entire industry, or related industries, but one individual site. Different industrial sites in North Korea house different chemical processes. The conclusions reached about the signatures of the chemical activities taking place at the Namhung Youth Chemical Complex, and thus the remote sensing tools that can be used to detect them, might not be applicable to the chemical processes taking place at other industrial sites of interest elsewhere in the country. That means this study's findings are likely to be limited to the processes and capabilities present at the chosen case study facility, or where comparable activities are taking place at other locations. Where different chemical processes with different signatures are present, alternative tools for assessment might be required.

Third, an assessment of the ability to track and determine historical changes to the complex using remote sensing has not been included. Although this work draws on both current and historical sources to build a picture and understanding of the site, the focus of the feasibility study is to support current and future assessments. It is possible that the purpose of the site has changed over time, perhaps once being more dedicated to CW production prior to having a primarily civil focus today. Therefore, the conclusions reached in this study will not support assessments of whether the case study site has *ever* supported a CW programme, but whether that capability is present today and in the future. Future work could explore potential traces of historic activities – for example, as a result of groundwater leaching – and whether remote sensing tools can support analysis in this way.

I. Case Study: The Namhung Youth Chemical Complex

THE NAMHUNG YOUTH Chemical Complex is a large chemical complex that has been a central part of the chemical industry in North Korea. The complex was built in the 1970s, using technology and equipment of French, Japanese and West German origin.³¹ It is a major producer of a range of chemicals for agriculture and other civil industries. Located near the city of Anju in the west of North Korea, the complex is sometimes also referred to as the Anju Youth Chemical Complex or the Namhung Chemical Factory. Since the 1970s, the complex has been an active site with regular expansion and modernisation that still takes place today.

Figure 1: Overview of the Namhung Youth Chemical Complex



Source: *Unearth Labs* <<https://www.uneearthlabs.com/>>, accessed 11 February 2022. Annotation added by authors.

31. NTI, 'Facilities', <<https://www.nti.org/learn/facilities/609/>>, accessed 1 July 2021.

Domestically in North Korea, the Namhung Youth Chemical Complex is an important site. All three North Korean leaders have visited the complex. The most recent was a visit by Kim Jong Un in 2013, but Pak Pong Ju and Kim Jae Ryong³² have also visited on a regular basis, with multiple visits reported early in 2020,³³ in the context of inspecting key areas of the national economy. This, however, should be placed in the appropriate domestic context of food insecurity, and the significance the regime has placed on the chemical industry – particularly building a C1 chemical industry – in developing North Korean agriculture, industry and economy.³⁴ Despite its clearly central role in the civil chemical industry,³⁵ it is not certain that the Namhung Youth Chemical Complex had, or still has, a role in the production or maintenance of CW. However, various sources have suggested that the complex has played a role in the production of chemical warfare agents or their precursors. These are discussed below.

The Nuclear Threat Initiative (NTI) has highlighted chemicals and processes present at the complex that could be used for CW activities, specifically ethylene oxide production capacity.³⁶ The NTI states that because of the presence of an ethylene oxide production capacity, 'blister agents or their immediate precursors could be produced here'.³⁷ However, this NTI resource does not explicitly account for the legitimate uses of ethylene oxide or consider how the focus of this facility may have changed over time.

Analysis by Joseph S Bermudez Jr argues that it is likely that the Namhung complex is at least involved in producing precursors relevant to CW, and possibly direct production of blood agents, but that it is also possible that precursors are sent to different locations for weapons production.³⁸ Bermudez acknowledges that a significant expansion of the complex might have resulted in North Korea's ability to quantitatively and qualitatively improve its CW capability.³⁹

32. Kim Jae Ryong and Pak Pong Ju are both senior North Korea officials. At the time of these visits, Kim Jae Ryong was a member of the Political Bureau of the Central Committee of the WPK, member of the State Affairs Commission and Premier of the Cabinet. Pak Pong Ju held similar credentials: at the time of these most recent site visits, he was a member of the Presidium of the Political Bureau of the Central Committee of the WPK, vice-chairman of the State Affairs Commission and vice-chairman of the WPK Central Committee.

33. See *KCNA*, 'DPRK Premier Inspects Various Fields of National Economy', 4 February 2020; *KCNA*, 'Pak Pong Ju Inspects Hwanghae Iron and Steel Complex and Namhung Youth Chemical Complex', 5 June 2020; *KCNA*, 'Kim Jae Ryong Inspects Different Units of National Economy', 7 June 2020.

34. C1 refers to small molecules containing one carbon, such as carbon monoxide and methanol. These simple compounds are versatile building blocks for the manufacture of a wide variety of chemicals.

35. Hamish Macdonald, 'Could N. Korea's C1 Chemistry Industry Enhance Its Self-Sufficiency?', *NK News*, 14 June 2017, <<https://www.nknews.org/2017/06/could-n-koreas-c1-chemistry-industry-enhance-its-self-sufficiency/>>, accessed 3 August 2021.

36. NTI, 'Facilities'.

37. *Ibid.*

38. Bermudez, 'North Korea's Namhung Youth Chemical Complex'.

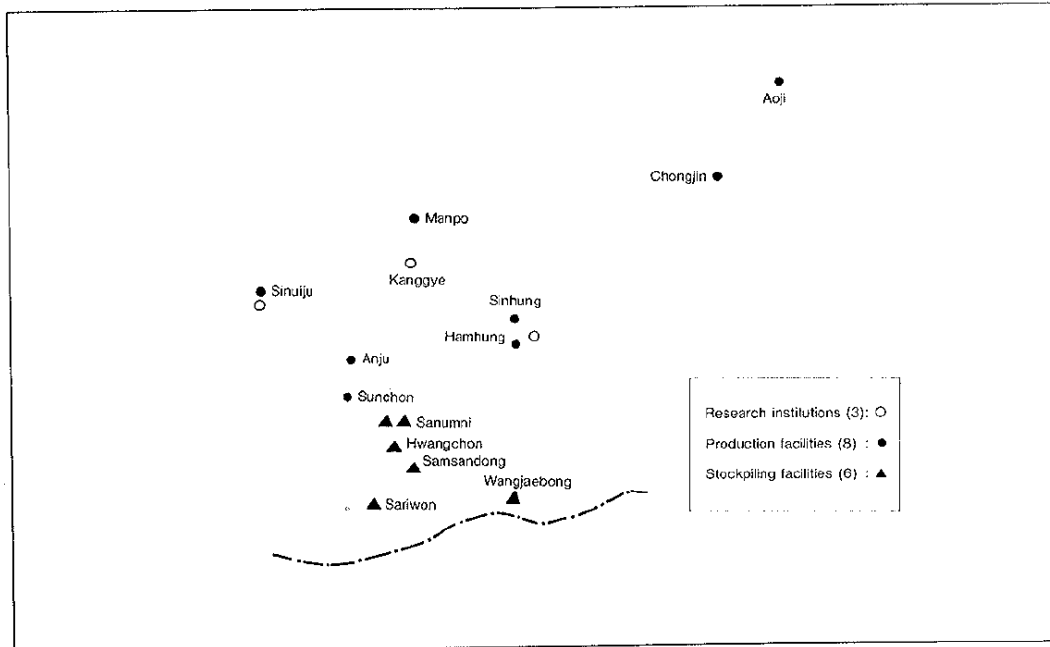
39. *Ibid.*

However, public resources do not provide a more in-depth look at specific chemical processes, the capacity of the Namhung complex or the quality of these processes.

Governmental sources have also linked the Namhung complex to a CW programme. Since the 1990s, the South Korean Ministry of National Defense white papers have reduced the amount of information included in relation to its assessments of North Korea’s CW capability. The 1990, 1991–92 and 1992–93 white papers include a map of what they assess to be research institutions, production facilities and stockpiling facilities related to CW in North Korea. This map includes a production facility at Anju. It would be reasonable to assume that this is the Namhung Youth Chemical Complex, although specific facility names are not included. All three of these reports also state that North Korea has produced and stockpiled, in large quantities, such agents as blister, nerve, choking, blood and tear gas.⁴⁰ Figure 2, taken from the 1990 document, shows the locations of three key site types in the North Korean CW programme: research institutions (three sites); stockpiling facilities (six sites); and production facilities (eight sites).

Figure 2: Assumed North Korean Chemical Weapon Production and Storage Facilities, 1990

Diagram 2-15. North Korean Chemical Weapon Production and Storage Facilities



Source: Ministry of National Defense of South Korea, ‘Defense White Paper’, 1990, p. 74.

40. MND, ‘Defense White Paper’, 1990, p. 73; MND, ‘Defense White Paper’, 1991–92, p. 97; MND, ‘Defense White Paper’, 1992–93, p. 71.

In South Korea's 1994–95 defence white paper, the map of CW-related sites is omitted. The paper instead refers to eight factories that produce 'most of the agents it [North Korea] possesses'.⁴¹ Similar language is repeated in the 1998 white paper,⁴² before changing in 1999 to also include four research facilities and six storage facilities, in addition to the eight chemical factories 'for mass producing chemical agents'.⁴³ The language changed again in 2000 to state 'eight different factories in North Korea have produced lethal chemical agents ... and at present they are stored in six different facilities',⁴⁴ suggesting uncertainty around the active production effort at the time. Since 2004, South Korean defence white papers have reported that '2,500–5,000 tons' of chemical agents are stored at 'facilities scattered around the country'.⁴⁵ Although earlier white papers refer to a site at Anju suspected to be related to CW production, the role Namhung Youth Chemical Complex had or still has in a CW programme remains unclear.

US governmental sources have not publicly linked the Namhung complex to CW production activities. Although documents have highlighted the chemical industry in North Korea as a potential route to CW,⁴⁶ they have not specifically referenced the complex. The Anju Chemical Youth Plant is classified as 'industrial activity' in CIA documents.⁴⁷ However, declassified documents that cover the chemical industry and processes in North Korea do refer to other chemical sites. For example, a declassified CIA report from 1962 details ammonia and sulfuric acid production occurring at the Hungnam Fertilizer Factory, another industrial site with a potential CW role, in quantities beyond what was deemed required for the North Korean chemical industry.⁴⁸

The absence of US government reporting on Namhung neither disproves nor proves any weapons role the complex might have, especially as such documents likely represent a snapshot of a period and not a comprehensive overview of activity. This is particularly important for facilities that maintain dual-use processes and materials. It is also worth questioning whether the US would publicly reference a determination on the role of this site or declassify historical sources if it was still considered a CW concern. Equally, the information might be lacking as a result of the absence of concern. Declassified documents relating to other industrial chemical sites that have been linked to potential CW production in non-governmental literature are heavily redacted, but a declassified US Interagency Intelligence Assessment from 1985 does highlight

41. MND, 'Defense White Paper', 1994–95, p. 70.

42. MND, 'Defense White Paper', 1998, p. 65.

43. MND, 'Defense White Paper', 1999, p. 57.

44. MND, 'Defense White Paper', 2000.

45. This overview omits the 1993–94 and 2001 MND white papers as the original sources cannot be found at this time.

46. CIA, 'North Korea: Offensive Chemical Warfare Capability', Interagency Intelligence Assessment, 28 March 1985.

47. CIA, 'Annual Index to Photographic Exploitation Production January-December 1978', March 1978; CIA, 'Annual Index to Photographic Exploitation Products January-December 1980', June 1981. The chemical and biological warfare sections of these documents are fully redacted.

48. CIA, 'The North Korean Chemical Industry', April 1962.

the risk and potential for the chemical industry in North Korea to play a role in producing CW,⁴⁹ meaning the potential role of Namhung in this effort should not be discounted.

North Korean defectors have also linked the complex to a CW programme. For example, in the 1990s, Yi Chung Kuk, a former sergeant in the Korean People's Army Nuclear Chemical Defense Bureau, stated that Namhung 'exclusively produces chemical weapons in a number of factories ... this is a weapons factory that researches, develops and produces various chemical weapons'.⁵⁰ While it is possible that the purpose of the complex might have changed between prioritising military and civil ends, or balancing both, there is little evidence to suggest that it is solely a weapons-focused facility at present. It is, of course, not possible to verify such defector reports and confirm the past focus of the complex.

Maintenance and electricity supply are two issues that have hampered operations at Namhung at various points in time. During the mid-1990s, North Korea sought funding from abroad to support repairs.⁵¹ From around 2006 to 2014, however, and with smaller improvements and upgrades still going on today, North Korea was able to undertake a large modernisation and expansion effort at Namhung.⁵² State media has also recently referenced that 'large compressors, pressure blowers and accessories' provided to the complex are from the Ryongsong Machine Complex and the Ragwon General Machine Enterprise,⁵³ and equipment is also reportedly provided by the Taean Heavy Machine Complex.⁵⁴ This might suggest that the complex does not solely rely on imported equipment for its operations.

In addition to equipment maintenance and repairs, the supply of electricity has also impeded the operations of the complex.⁵⁵ In early 2020, the *Pyongyang Times* reported that the Namhung Youth Chemical Complex had 'built a power generation process with a capacity of well over 10,000 kW by rationally remodelling the process of treating steam of a large boiler for the supply of steam for fertilizer production'.⁵⁶ It is reported that the complex largely relied on imported fuel and a nearby thermal power station, but is now able to rely on 'domestic materials alone for its operation'.⁵⁷

49. CIA, 'North Korea: Offensive Chemical Warfare Capability'.

50. Cited in Bermudez, 'North Korea's Namhung Youth Chemical Complex'.

51. Bermudez, 'North Korea's Namhung Youth Chemical Complex'.

52. KCNA, 'KCNA Issues Detailed Report on Grand Socialist Construction Drive', 13 December 2013.

53. *Voice of Korea*, 'Production of Ordered Equipment Promoted at Machine-Building Bases', 21 August 2020.

54. *Pyongyang Times*, 'Heavy Machine Giant Steps Up Custom-Built Equipment Production', 9 November 2020.

55. Bermudez, 'North Korea's Namhung Youth Chemical Complex'.

56. *Pyongyang Times*, 'Electricity Production Process Established at Fertilizer Factory', 26 January 2020.

57. *Naenara*, 'Confident in Their Future', 5 May 2014.

Chemical Activity at the Namhung Youth Chemical Complex

The Namhung Youth Chemical Complex has been described as the largest petrochemical facility in North Korea, and reportedly has an annual chemical production capacity of '550,000 tons'.⁵⁸ It has been labelled as a 'leading chemical industry base' within North Korea,⁵⁹ and according to state media, 'today it is in a position to turn out hundreds of kinds of quality chemicals'.⁶⁰ North Korean media has also reported that the complex focuses on fertiliser production for the agricultural sector, and produces 'well over 1,000 tons on a daily average'.⁶¹

To make an informed assessment regarding the capacity or capability of a chemical facility and its potential role in CW activities, it is important to understand as much about the complex as possible. This includes treating explicitly non-CW related processes and chemicals with just as much interest as those that might have weapons relevance. Without this, it will be difficult to build a robust picture of the site and its activities. Furthermore, without a comprehensive understanding of the purported activities, it will not be possible to develop plausible hypotheses about any potential CW capability, or identify traits and signatures that could be detectable using remote sensing tools.

The chemical products identified at Namhung are derived from either naphtha or anthracite coal feedstocks. It appears that, over time, North Korea's focus has shifted from naphtha (produced from refining imported crude oil) to coal, whose indigenous reserves are abundant.⁶² The naphtha feedstock for the naphtha cracking centre (NCC) was assumed to reach the site through pipelines from either the Ponghwa/Bonghwa Chemical Factory,⁶³ or from both Ponghwa and Sungni Chemical Factories.⁶⁴ However, recent reports in North Korean state media have said that the Namhung complex has replaced its use of naphtha with anthracite coal gasification.⁶⁵ There have also been mentions of naphtha being imported for fertiliser production.⁶⁶ The chemical

58. Louise Waldenström, Lena Norlander and Gertrud Puu, *North Korea's Chemical and Biological Weapons Programmes in 2005: Real or Outdated Threats?* (Stockholm: FOI, 2005).

59. *Naenara*, 'Full of Pride and Confidence', 13 April 2018.

60. *Naenara*, 'Namhung Youth Chemical Complex', 14 November 2018.

61. *Pyongyang Times*, 'Nation Set on Juche-Oriented Metal and Chemical Industries', 2 February 2019.

62. David von Hippel and Peter Hayes, 'DPRK Investments in Coal Gasification Driven by Long-Run Juche and Sanctions Proofing', NAPSNet Special Reports, 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 28 February 2022.

63. Waldenström, Norlander and Puu, *North Korea's Chemical and Biological Weapons Programmes in 2005*.

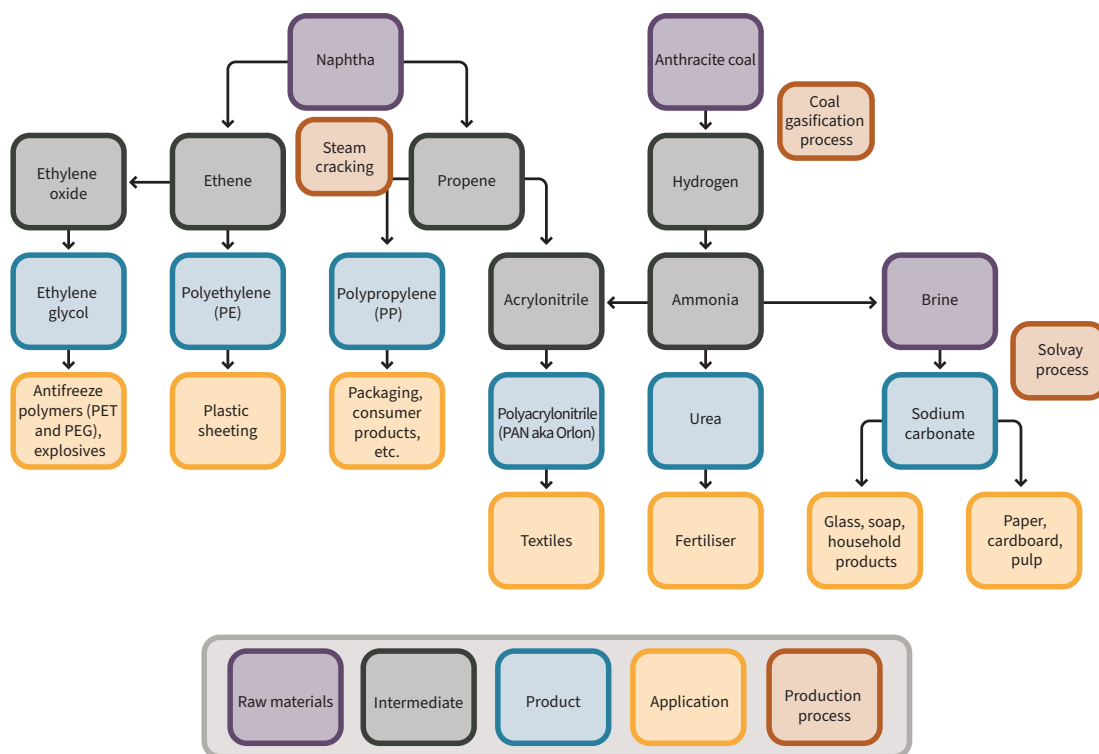
64. NTI, 'Facilities'.

65. *Pyongyang Times*, 'Modernization Boosts Fertilizer Production', 14 May 2015; *Naenara*, 'New Fertilizer Production System Established', 22 August 2016.

66. *Ibid.*

process flows from both naphtha and anthracite coal are discussed below, with an overview of the chemical processes understood to be present at the complex summarised in Figure 3.

Figure 3: Overview of Reported Production at the Namhung Complex



Source: Author generated.

Naphtha Feedstock

Early chemical production at the complex is likely to have centred around the NCC, a steam cracker whose construction was reportedly completed in 1979.⁶⁷ Steam crackers break the naphtha feedstock into smaller, useful and valuable chemicals. Three of these valuable chemicals – ethene, propene and hydrogen – are used to produce a number of chemical products at Namhung.

67. IBP USA, *Korea North Export-Import Handbook: Volume 1: Strategic, Practical Information, Contacts* (Washington, DC: IBP USA, 2010).

Ethene

There are two chemicals reportedly produced at the complex which would use ethene as a feedstock: polyethylene and ethylene oxide.⁶⁸ The polyethylene is used for greenhouse sheeting, whose production is seen in some videos of the site. Videos that were online at the time of research showed this plastic product,⁶⁹ and although the date of filming has not been established, it is plausible that the cracker is still operational today. The ethylene oxide plant was one of the original production plants at the site, with construction completed in 1979.⁷⁰ It uses Japanese equipment,⁷¹ possibly imported from Japan Catalytic.⁷² Ethylene oxide is a common industrial intermediate, usually produced and consumed in situ as it is highly reactive and hazardous.⁷³ It is likely that some, if not all, ethylene oxide is converted to ethylene glycol and, although no North Korean end use is specified, this is used as an automotive antifreeze and refrigerant, and in the production of explosives and polyethylene terephthalate (PET), one of the most common plastics.⁷⁴ A recent news article suggests that ethylene glycol may be used in North Korea to produce an additive for building materials.⁷⁵ Reporting refers to an ethylene glycol plant at Namhung.⁷⁶ It should be noted that ethylene oxide has been used as an insecticide in many countries in the past⁷⁷ and, while mainly phased out, is still used even today.⁷⁸

Propene

The second chemical derived from the naphtha feedstock is propene. Propene appears to be consumed in two processes: production of polypropylene and production of acrylonitrile.⁷⁹ The end use of polypropylene is not specified in the reporting, but this is another common plastic with a large number of applications. Acrylonitrile is subsequently polymerised to form

68. *Ibid.*

69. These videos have since been taken offline.

70. IBP USA, *Korea North Export-Import Handbook*.

71. NTI, 'Namhung Youth Chemical Complex', last updated 1 March 2003, <<https://nautilus.org/napsnet/napsnet-special-reports/dprk-investments-in-coal-gasification-driven-by-long-run-juche-and-and-sanctions-proofing/>>, accessed 28 February 2022.

72. Siegfried Rebsdat and Dieter Mayer, 'Ethylene Oxide', in *Ullmann's Encyclopedia of Industrial Chemistry* (Weinheim: Wiley-VCH, 2001).

73. *Ibid.*

74. Siegfried Rebsdat and Dieter Mayer, 'Ethylene Glycol', in *Ullmann's Encyclopedia of Industrial Chemistry*.

75. *Pyongyang Times*, 'PET Waste Recycling Technology Established', 18 July 2020.

76. IBP USA, *Korea North Export-Import Handbook*.

77. Inchem, 'WHO Pesticide Residues Series, No. 1', 1971, <<http://www.inchem.org/documents/jmpr/jmpmono/v071pr15.htm>>, accessed 23 August 2021.

78. Leo Frühschütz, 'Pesticide Findings in Organic Sesame from India', 21 December 2020, <<https://organic-market.info/news-in-brief-and-reports-article/pesticide-findings-in-organic-sesame-from-india.html>>, accessed 23 August 2021.

79. IBP USA, *Korea North Export-Import Handbook*.

polyacrylonitrile (PAN) – also known by the trade name Orlon – and referred to in reporting on Namhung. PAN is spun into fibres and used for textiles. The spinning mills can be seen in videos of the complex.⁸⁰ However, acrylonitrile is also of relevance for CW production, as discussed further below.

Hydrogen

Reporting indicates that hydrogen gas from the NCC was used to produce ammonia, a chemical fundamental to nitrogenous fertiliser production. North Korea relies heavily on fertiliser for agriculture, and has introduced 'technical innovation plans' to increase fertiliser yields.⁸¹

Coal Feedstock

After the Cold War ended, cheap crude oil was no longer readily available to North Korea and its focus turned to replacing the naphtha feedstock with its abundant indigenous coal reserves. Coal gasification technology, commonly used to generate electricity, has been employed by North Korea to augment its fertiliser production and there are reports that two gasification plants have now been constructed and commissioned at Namhung.⁸²

The gasification process provides a source of hydrogen gas for ammonia production. The ammonia is reportedly consumed in three subsequent production routes, synthesising urea, acrylonitrile (discussed above) and sodium carbonate.

Urea

Urea is used as a fertiliser and is seen as a white crystalline powder in various videos and photos from the complex.⁸³ It is packaged in 50-kg bags marked with 46% (the percentage of nitrogen content).⁸⁴ Urea may also be used in the production of explosives, although North Korea's food shortages and need for fertiliser may preclude other end uses.

80. See, for example, '목란 현지방송 . 남흥이 들끓는다 – 남흥청년화학연합기업소' ['Local Broadcast, Namhung Is Seething, Namhung Youth Chemical Co., Ltd'], YouTube, 9 April 2021, <<https://www.youtube.com/watch?v=iepjx489Clc>>, accessed 23 August 2021.

81. *Pyongyang News*, 'Giants Produce Hundreds of Thousands of Tons', 8 June 2019.

82. *KCNA*, 'Kim Jong Il Gives Field Guidance to Namhung Youth Chemical Complex', 7 May 2011.

83. See, for example, Choson Sinbo, '〈자력갱생의 기치높이 전진하는 조선의 현장들 7〉 남흥청년화학연합기업소를 찾아서' ['Sites of Choson Advancing with a High Banner of Self Reliance'], YouTube, 10 July 2019, <<https://www.youtube.com/watch?v=n4rHxN3FEOU>>, accessed 23 August 2021.

84. *Ibid.*

Sodium Carbonate

Sodium carbonate may be used in the production of paper and pulp, and there is a paper mill located in the western part of the complex.⁸⁵ It is not clear whether it is still operational. Other suggested uses of sodium carbonate in North Korea are the production of glass, dyes, soap, medicine and food products.⁸⁶ The sodium carbonate plant at the complex is sometimes referred to as the sodium bicarbonate plant⁸⁷ – sodium bicarbonate is converted to sodium carbonate in the last step of production.

Sodium carbonate at the complex is 'made from edible sodium and limestone with ammonia as the catalyst'⁸⁸ and therefore appears to be based on the common industrial Solvay process (or similar Hou process), using a brine (sodium chloride) solution as a raw material. However, there are aspirations to rebuild the plant and use the indigenous mineral glauberite (sodium calcium sulfate) as a raw material instead.⁸⁹ The intention is to use glauberite to produce sulfuric acid, sodium hydroxide (caustic soda) and calcium sulfate (gypsum) as well.⁹⁰ Two other products relating to the sodium carbonate plant have been reported: sodium lactate;⁹¹ and sodium percarbonate.⁹² Sodium lactate has been associated with the sodium carbonate plant and it may be produced from the reaction of sodium carbonate with lactic acid. It is not clear if sodium percarbonate is produced at Namhung, but it is plausible as it is a simple adduct of sodium carbonate and hydrogen peroxide.

85. Joseph S Bermudez Jr, 'The Namhung Industrial Area: Overview', *38 North*.

86. Yonhap News Agency, *North Korea Handbook* (Armonk, NY: M E Sharpe, 2003).

87. Bermudez, 'North Korea's Namhung Youth Chemical Complex'.

88. Yonhap News Agency, *North Korea Handbook*.

89. *Pyongyang Times*, 'Big Efforts Put into Chemical Industry Building', 23 May 2020.

90. *Ibid.*

91. Shim Wan-seop, Lee Seok-gi and Lee Seung-yeop, '북한의 화학산업 역량 재평가와 남북경협에 대한 시사점' ['Reassessment of North Korea's Chemical Industry Capabilities and Implications for Inter-Korean Economic Co-Operation'], Korean Institute for Industrial Economics and Trade, 2015.

92. Foreign Trade Publishing House, *Foreign Trade of the Democratic People's Republic of Korea: Volume 3* (Pyongyang: Foreign Trade Publishing House, 2016).

A Chemical Weapons Risk?

Table 1: Chemical Weapons Precursors and Their Availability at Namhung

CW Agent		Immediate Precursors	Precursor Starting Materials (Where Applicable)	Potential Availability at Namhung	
Blood agents	Hydrogen cyanide	Known by-product from industrial acrylonitrile production*		✓✓	
	Cyanogen chloride	Chlorine [†]		??	
		Hydrogen cyanide		✓✓	
Blister agents	Nitrogen mustard HN3	Triethanolamine	Ammonia [‡]	✓✓	
			Ethylene oxide [§]	✓✓	
		Chlorinating agent		××	
	Nitrogen mustard HN2	N-methyl diethanolamine		Methanol	××
				Ammonia	✓✓
				Ethylene oxide	✓✓
		Chlorinating agent		××	
	Nitrogen mustard HN1	N-ethyl diethanolamine		Ethanol	××
				Ammonia	✓✓
				Ethylene oxide	✓✓
		Chlorinating agent		××	
	Sulfur mustard	Thiodiglycol		Ethylene oxide	✓✓
				Hydrogen sulfide [¶]	??
Chlorinating agent			××		

Key: ✓ Plausible that this chemical is available, providing the associated production plant is operational.

? No direct evidence to suggest the chemical is available, but it is associated with a production process that may be taking place.

× No open source evidence found to suggest the chemical is available.

Sources: * James F Brazdil, 'Acrylonitrile', in Ullmann's Encyclopedia of Industrial Chemistry; IBP USA, Korea North Export-Import Handbook; † Pratima Bajpai, Biermann's Handbook of Pulp and Paper, Volume 1: Raw

Material and Pulp Making, 3rd edition (London: Elsevier, 2018); Peace Times, 'Choi Jae-young's Story of a North Korean Worker Episode 7'; ‡ Yonhap, 'N. Korean Firm Begins Fertilizer Production Using Anthracite'; KCNA, 'Kim Jong Il Gives Field Guidance to Namhung Youth Chemical Complex'; § IBP USA, Korea North Export-Import Handbook; ¶ Chris Higman and Maarten van der Burgt, Gasification (London: Elsevier, 2008).

Blood Agents

A number of reports refer to blood agents – such as hydrogen cyanide or cyanogen chloride – being produced at Namhung (or in North Korea more generally).⁹³ This is certainly plausible as hydrogen cyanide (also known as prussic acid) is a significant by-product in the synthesis of acrylonitrile.⁹⁴ The production capacity for the acrylonitrile plant is reported to be 10,000 tonnes per year⁹⁵ and, based on the production ratio (10 acrylonitrile : 1 hydrogen cyanide),⁹⁶ approximately 1,000 tonnes of hydrogen cyanide could theoretically be produced per year. However, the actual annual quantity of acrylonitrile produced is unknown, and there is no reporting which confirms whether the production plant remains operational. Although acrylonitrile production provides an ideal opportunity to produce CW agents, the handling, transportation and long-term storage of hydrogen cyanide presents many challenges.⁹⁷ Unstabilised hydrogen cyanide is a severe explosion hazard and can polymerise violently. Water content of hydrogen cyanide solutions is critical: anhydrous (dry) hydrogen cyanide is a severe explosion hazard, yet solutions containing more than 4–5% water are even more hazardous than the anhydrous chemical. Large quantities should be maintained at 5°C or below (elevated temperatures can lead to explosive polymerisation), permanently recirculated and the colour of the liquid monitored. Cylinders of hydrogen cyanide should not be stored for longer than a year,⁹⁸ although some industry sources suggest that their shelf life is as short as 90 days.⁹⁹

Cyanogen chloride can be produced by the reaction of chlorine with hydrogen cyanide.¹⁰⁰ There is no reporting to suggest that this is produced at Namhung and nothing to confirm the availability of chlorine at the site. It is, however, possible that chlorine is used for bleaching during the paper and pulp production process.¹⁰¹ Cyanogen chloride has a number of legitimate

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93. Bermudez, 'North Korea's Namhung Youth Chemical Complex'; Waldenström, Norlander and Puu, *North Korea's Chemical and Biological Weapons Programmes in 2005*; MND, 'Defense White Paper', 1990; MND, 'Defense White Paper', 1991–92; MND, 'Defense White Paper', 1992–93.
94. Brazdil, 'Acrylonitrile'.
95. IBP USA, *Korea North Export-Import Handbook*.
96. Brazdil, 'Acrylonitrile'.
97. Ernst Gail et al., 'Cyano Compounds, Inorganic', in *Ullmann's Encyclopedia of Industrial Chemistry*.
98. *Ibid.*
99. PubChem, 'Hydrogen Cyanide', <<https://pubchem.ncbi.nlm.nih.gov/source/hsdb/165>>, accessed 26 August 2021.
100. Gail et al., 'Cyano Compounds, Inorganic'.
101. Bajpai, *Biermann's Handbook of Pulp and Paper*.

industrial uses and is usually consumed immediately after preparation: it is not usually stored. If it is stored, it must be very pure and mixed with a stabiliser to prevent violent polymerisation.¹⁰²

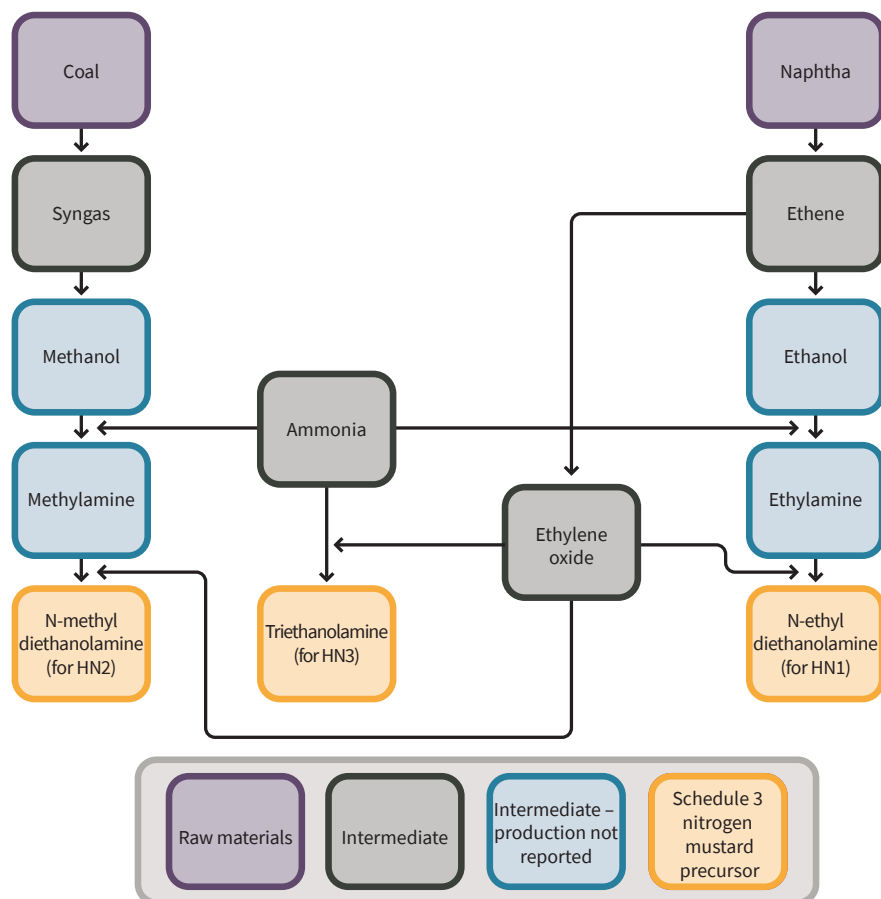
Blister Agents

As noted above, the ethylene oxide plant is widely cited as possible evidence of CW production at the complex. The plant has a reported production capacity of 10,000 tonnes per year.¹⁰³ Ethylene oxide can be used to synthesise ethanolamines, the key precursors of nitrogen mustards (see Figure 4). In terms of production at the complex, it is possible that triethanolamine – a Schedule 3 nitrogen mustard precursor – could be produced as both ethylene oxide and ammonia are readily available.¹⁰⁴ There is no evidence to confirm the presence of either the alcohols (methanol and ethanol) or the amines (ethylamine and methylamine) at Namhung for production of the other nitrogen mustard precursors.

102. Gail et al., 'Cyano Compounds, Inorganic'.

103. IBP USA, *Korea North Export-Import Handbook*.

104. A full list of Schedule 3 chemicals can be found at OPCW, 'Annex on Chemicals: Schedule 3', <<https://www.opcw.org/chemical-weapons-convention/annexes/annex-chemicals/schedule-3>>, accessed 11 February 2022.

Figure 4: Production Process of Nitrogen Mustard Precursors

Source: Author generated.

Ethylene oxide can also be reacted with hydrogen sulfide to produce thiodiglycol, a key sulfur mustard precursor and Schedule 2 chemical.¹⁰⁵ While hydrogen sulfide does not appear to be intentionally produced at the site, it is generated as a by-product of the coal gasification process.¹⁰⁶ It is possible it could be captured and used to produce thiodiglycol.

There is no suggestion that there are suitable chlorinating agents available at Namhung that could be used to convert the sulfur and nitrogen mustard precursors to the agents themselves. However, chlorine chemistry is extensively employed at the February 8 Vinalon Complex (another significant chemical site in North Korea),¹⁰⁷ with a reported production capacity of 300,000

105. A full list of Schedule 2 chemicals can be found at OPCW, 'Annex on Chemicals: Schedule 2', <<https://www.opcw.org/chemical-weapons-convention/annexes/annex-chemicals/schedule-2>>, accessed 11 February 2022.

106. Higman and Burgt, *Gasification*.

107. NTI, 'Facilities'.

tonnes of chlorine and hydrochloric acid per year.¹⁰⁸ It is possible that the CW precursors are transferred to another site for agent production. Indeed, a report from the Korea Institute for Defense Analyses suggests CW production in North Korea is grouped into basic, intermediate and final agents, and Namhung is classified as basic.¹⁰⁹ This could indicate involvement in early precursor production.

While the production of ethylene oxide is of potential CW relevance, there is no evidence to confirm whether the plant is still operational, and it has not been publicly identified. It seems logical that the ethylene oxide plant (and ethylene glycol plant) would be located in the vicinity of the NCC, and also the polyethylene and polypropylene plants. This collocation would minimise the amount of pipework required to transfer the ethylene and propylene cracker products around the site. According to Bermudez, there is a petrochemical plant on the southern part of the complex which merits further examination.¹¹⁰ Pipework is seen to link the main and southern parts of the site, crossing the railway line.

In addition to consideration of chemical processes with potential CW relevance, the equipment used should also be assessed. North Korean state media reporting and YouTube videos linked to the state have provided some ground imagery of the site.¹¹¹ Consideration of known industrial production routes has also enabled key equipment and infrastructure associated with such processes to be determined. Based on the equipment expected to be involved in the production processes identified, and a limited imagery review, it would appear that a lot of the equipment is specialised and dedicated, often using continuous processes. This type of equipment, combined with continuous production processes, affords less flexibility and is thus more difficult to adapt for other purposes (such as CW agent production) than multi-purpose equipment using batch processes. It should also be noted that plants exclusively producing hydrocarbons (such as crackers) or polymers are not subject to declaration and on-site inspection under the CWC as these are of no dual use concern. Furthermore, urea plants are also now considered as low relevance under the CWC's verification regime.

By using open source research to break down and analyse the chemical processes taking place at the complex, it can be assessed that defector reporting characterising the site as 'exclusively' producing CW agents is unlikely to be accurate. However, this analysis does demonstrate that some of these processes are relevant to the production of a limited range of CW agents. The

108. NTI, 'February 8th Vinalon Complex', <<http://web.archive.org/web/20170806090539/https://www.nti.org/learn/facilities/603/>>, accessed 23 August 2021.

109. Korea Institute for Defense Analyses (KIDA), *동북아 군사력과 전략동향 [Northeast Asia Military Power and Strategic Trends]* (Seoul: KIDA Press, 2015).

110. Bermudez, 'North Korea's Namhung Youth Chemical Complex'.

111. See, for example, Choson Sinbo, '〈자력갱생의 기치높이 전진하는 조선의 현장들 7〉 남흥청년화학연합기업소를 찾아서' ['Sites of Choson Advancing with a High Banner of Self-Reliance']; *Pyongyang Times*, 'Chemical Giant Hastens Technical Upgrading of Production Lines', 26 March 2020.

following section discusses the gaps in the authors' current study and how these might be plugged using remote sensing tools.

Signatures and Remote Sensing

Based on the above assessment, there is no doubt that the Namhung Youth Chemical Complex is operating a number of purely civil activities. However, the authors' analysis has also identified multiple processes present at the complex that are relevant for the production of vesicant precursor chemicals and toxic Schedule 3 chemicals and therefore warrant further investigation. The authors have not been able to fully implement and utilise remote sensing tools to support analytical assessments regarding activities at the complex, but have identified a number of ways in which remote sensing would benefit this analysis.

Chemical processes have signatures that result from the chemical reaction(s) taking place, and these could include heat, corrosion, emissions and waste. Different chemical processes will produce these signatures to varying degrees. The authors' initial research suggests that it is increasingly feasible for remote sensing tools to contribute to analysis of the chemical processes taking place by monitoring these signatures. This will help to corroborate or challenge reported activities, identify which signatures are present in which parts of the complex and better understand the chemical activities that could be taking place. Remote sensing tools can also help identify unexpected signatures and discrepancies between signatures detected and activities reported. This can be supported by ground imagery and video to better understand the implementation of chemical processes and develop assessments based on what is visible from inside the buildings shown.

In this context, however, the scale of production will be an important consideration. North Korean sources suggest that the complex is capable of producing '550,000 tons' of chemicals each year and there is a high demand for fertiliser – this is a large-scale production facility. It is possible that CW agents are only produced in much smaller quantities, and this would certainly be true if the focus was on stockpile maintenance and sustainment, rather than growth. This could further complicate the detection of signatures. The authors would not be able to conclude that activities necessary for CW production are not taking place, just that they are not present on a scale that is detectable – which in itself is a useful conclusion.

Broadly, there are two ways in which remote sensing could contribute to analysis. First, remote sensing tools can help develop a general understanding of the complex, how active it is and how certain areas of the site are linked together. Second, remote sensing could help develop and refine the authors' hypotheses about the complex through the identification and analysis of specific signatures which can inform assessments of the activities.

The authors' initial research has identified three primary remote sensing tools that could be helpful in furthering their analysis: optical imagery; thermal infrared imagery; and hyperspectral imagery. Through expert workshops involving chemical engineers, weapons experts and remote sensing experts, these tools were recognised as the most appropriate starting place for assessing

the signatures of the processes that were identified. These discussions did not cover all possible remote sensing tools, but instead focused on the activities identified, the signatures they will likely have and the most appropriate tools that could be used to support analytical assessments. This means that the discussion of capabilities below is not exhaustive, and there will likely be other remote sensing tools that could contribute to an expanded study. However, these tools will indicate the minimum level of remote sensing capability that could be deployed to support assessments of North Korea's chemical industry and its potential role in CW production.

The remote sensing opportunities discussed below are not all mutually exclusive, and many overlap. Together, they can contribute different parts of the jigsaw puzzle that can be drawn on to develop hypotheses and assessments about the site and its potential CW risk.

Optical Imagery

One of the primary next steps in strengthening the authors' analysis of the complex would be to map the production processes identified above to specific areas, facilities, utilities and buildings. Optical imagery analysis can be a useful tool in this regard. Optical imagery uses the light spectrum to produce images of the earth and objects. It is a passive technology, meaning that it does not need to transmit a signal to produce an image, but instead uses natural light. Of course, this creates limitations, making its application reliant on daylight and clear skies to see what is below. When optimal conditions are present, however, commercial optical imagery can produce high spatial resolution images, down to 30 cm–5 m for images with high or very high resolution. Images at this resolution can support the identification of objects such as buildings and infrastructure.

While chemical processes largely take place inside buildings, optical imagery can be used to identify key ancillary equipment located nearby, and distinctive features on buildings that may indicate the type of process taking place inside. For example, optical imagery could be used to identify signs of corrosion, an incinerator for waste treatment or possibly scrubber systems used to treat hazardous gaseous emissions. It could also be used to identify the type of ventilation system present from exhaust fans on walls or the roof, or external ducting, giving an indication of a hazardous process taking place. Open source ground imagery of the complex, including imagery that shows specific equipment and internal building details, can also be used to identify and locate specific reported activities taking place at the complex. Off-nadir imagery – imagery taken at an angle rather than from directly above the area of interest – would be beneficial here and help with observing specific building features. Optical imagery could be used to identify storage areas, such as tank farms, and any specialised storage vessels or transport containers.¹¹² However, as noted above, this will require high-resolution imagery that will be infrequent and expensive.

112. Previous work by Joseph S Bermudez Jr has begun to identify key parts of the site, including a separate storage area. See Bermudez, 'North Korea's Namhung Youth Chemical Complex'.

Comparison of optical imagery with known and characterised production plants may be used to corroborate assessment of the activities at Namhung, and highlight any unexpected differences. Of course, there is a need to consider which expected features might result from practical health and safety considerations in other jurisdictions, rather than being a necessity of the chemical process, and it should not be assumed that these same standards will apply in the North Korea context.

Optical imagery can also support the identification of corrosion that could be the result of certain chemical processes. First, corrosion might be visible due to the discolouration it causes. Observation of discolouration could be identified with medium-resolution imagery. Second, it could be inferred through the observance of regular replacement of external pipework, for example, and regular site activity that could be attributable to maintenance work. Although corrosion-resistant steel is widely preferred for working with ethylene oxide, which has been identified as present at the complex, a lower grade of steel can be used, albeit with a more regular need for maintenance and replacement. Such observations could help determine how the above chemical process flows map onto the site itself.

In addition to the identification of facilities, optical imagery can assist in observing whether there are any visible physical connections between facilities or buildings and thus be used to inform the authors' analysis of the processes around the complex. For example, as noted above, previous work has identified a petrochemical plant in the southern part of the complex. Imagery shows that there is pipework linking this area of the complex with the northeastern area, which is where the majority of the chemical activities are believed to take place (see Figure 5). Drawing on the assessments of the processes present and the flow chart of chemical activity, optical imagery can help map this onto the site itself. High-resolution imagery will make this task easier.

Figure 5: Pipework Connects the Southern and Northern Parts of the Complex



Source: *Unearth Labs*, <<https://www.unearthlabs.com/>>, accessed 11 February 2022. Annotation added by authors.

Optical imagery has also been identified as a useful way of contributing to the development of hypotheses relating to operating procedures and practices. The frequent collection and analysis of regular optical imagery would help to build a picture of general activity at the site and understand its pattern of life. Using optical imagery, observations can be made regarding vehicles, how frequently they are coming on and off site, and what type of vehicles they are. This, for example, could help the gathering of data points related to how often storage areas are emptied and refilled, which can provide an indication as to how active some processes are. As noted above, the scattering of chemical agent production across various industrial sites in North Korea is possible, and therefore monitoring and understanding patterns of site traffic, the type of transport going in and out, and its frequency is also of interest. This, however, is based on a best-case scenario, and there are limitations that should be acknowledged.

The availability of optical imagery is not constant, meaning there will be gaps in times and dates for which imagery is not available. To use optical imagery in this way will likely necessitate the tasking of commercial satellites. This will rely on analytical work to estimate when traffic might be present to capture it. For example, this could be developed by collating images across multiple dates and assessing changes in storage areas, which could suggest the presence of traffic. This is not an easy feat, as evidenced by other work that relies on accurate estimations of shipping

activity to capture imagery of potential sanctions evasion.¹¹³ The clarity and thus usefulness of the image could be hampered by poor weather. This will impact the completeness of such assessments, which at best might be circumstantial rather than indicative of broader patterns. For assessments of patterns, or the lack of them, to become more robust, a database of imagery and analytical assessments will need to be built up over long periods of time. Given these challenges, analyses of traffic patterns should not take precedence in the expansion of this work.

Furthermore, gaining a deeper understanding of operational status is not just beneficial to improving the understanding of site activities, but is also crucial for understanding irregularities or changes in patterns. Although it might not be possible to identify what has caused a change in activity, it is certainly worth monitoring. Identifying and monitoring general site activity would also be useful for corroborating other information sources and building hypotheses. For example, remote sensing could be contrasted with North Korean state media claims to help answer certain questions, such as whether the level of activity observed corresponds with the claims of high fertiliser production rates.

To support much of the activity outlined above, high-resolution imagery of at least 5 m a pixel would largely be required for successful analysis, with off-nadir imagery increasing opportunities to observe specific features. There has been a growth in the number of commercial providers able to offer high-resolution imagery in recent years, and this will have a positive impact on the ability to use such tools to build understanding of sites of interest.

Thermal Infrared Imagery

To support and bolster understanding of the complex, thermal infrared imagery could be used. This remote sensing technology could be employed in the context of assessing heating and cooling of particular buildings, which would suggest there is activity present. Commercial availability of this technology is still relatively new, with only a handful of operational sensors, generally with a quality lower than that available to states. The resolution of these images is also low, which in an area of closely developed buildings and infrastructure could make it difficult to assess the precise source of the temperature variance.¹¹⁴

Despite these shortcomings, thermal infrared imagery has contributed to assessments of North Korea's nuclear facilities, and could bring similar benefits if applied to industrial chemical sites.¹¹⁵

Infrared imagery collected over a period of time can help inform assessments of how frequently a particular facility might be operating as a result of the heat signatures emitted. When compared

113. See, for example, James Byrne et al., 'The Billion-Dollar Border Town: North Korea's Trade Network in Dandong (Part 1)', RUSI Project Sandstone, No. 7, September 2020.

114. Grace Liu et al., 'Eyes on U: Opportunities, Challenges, and Limits of Remote Sensing for Monitoring Uranium Mining and Milling', CNS Occasional Paper No. 44, Middlebury Institute for International Studies at Monterey, January 2019.

115. Bermudez et al., 'Thermal Imagery Indicates Activity at Yongbyon Nuclear Reprocessing Facilities'.

with analyses of other signatures, this could help inform hypotheses on plausible production capacities. Although this will not provide a silver bullet for assessing activities taking place within buildings, it can, for example, help provide supporting evidence to answering questions such as the presence of constant or intermittent activity.

Thermal infrared imagery could also identify and quantify temperature ranges for heat signatures of specific facilities. Using it will not only contribute to an understanding of whether certain facilities are showing heat signatures or cooling mechanisms – by identifying a temperature difference between the building and its surroundings – but could also provide insight into a fluctuation of activity throughout the year due to changes in the climate. For example, given the energy supply issues the Namhung complex has had, certain chemical processes that require cooling systems to be operated might only take place outside the high heat of summer as a result of a lack of consistently available electricity to operate a cooling system. This could impact production quantities.

Using a combination of optical imagery and thermal infrared imagery to gather data on how active the relevant parts of the complex are will also help to develop refined hypotheses regarding acrylonitrile production and thus potentially hydrogen cyanide. The production capacity for the acrylonitrile plant is reported to be 10,000 tonnes per year, which in theory could result in approximately 1,000 tonnes of hydrogen cyanide being produced per year. However, the actual annual production quantity of acrylonitrile is unknown, and there is no reporting which confirms whether the production plant even remains operational. Optical imagery could be used to identify facilities with relevant features for acrylonitrile production, and thermal infrared imagery could support identification of temperature-controlled areas within the complex.¹¹⁶ Although uncertainties would still remain and it would be unlikely that a definitive conclusion about acrylonitrile production or its volume could be reached, it might be possible to refine the authors' hypotheses to determine that the necessary features for present day production are present.

Hyperspectral Imagery

Hyperspectral sensors can provide data on chemical signatures by creating images from bands of light across the electromagnetic spectrum that are not visible to the human eye.¹¹⁷ At the moment, the ability to use hyperspectral imagery from satellite-based sensors is limited.¹¹⁸ Although the technology itself is established and has been used widely on UAVs, its application

116. As noted above, hydrogen cyanide should be stored at low temperatures. This will require temperature management systems to be in place that might have observable features such as back-up energy supplies to ensure the maintenance of stable temperatures.

117. For further information on this capability, see National Institute of Standards and Technology, 'Getting Hyperspectral Imaging Ready for the Rain Forest', 24 February 2016, <<https://www.nist.gov/news-events/news/2016/02/getting-hyperspectral-imaging-ready-rain-forest>>, accessed 7 February 2022.

118. For an overview of the current state of play, see Liu et al., 'Eyes on U'.

to satellites has been challenging¹¹⁹ due to the large datasets that satellites with this type of sensor would be required to store and transmit.¹²⁰ Hyperspectral imagery is a relatively limited commercial asset and thus its applications to WMD monitoring have not been widely explored or applied in the open source. Between 2000 and 2017, the Earth Observing-1 satellite was equipped with Hyperion, a hyperspectral sensor that was capable of collecting 220 spectral channels.¹²¹ This resulted in a limited database of images with low resolution.¹²² Despite the limited availability of hyperspectral sensors, some research has assessed the utility of this capability in the context of nuclear safeguards arrangements which concluded that there was promise in its use,¹²³ with varying utility across different parts of the nuclear fuel cycle.¹²⁴ Lessons from this work should be explored in the context of other WMD capabilities.

As an area of interest that is not amenable to UAV-based sensors, the use of hyperspectral imagery for the purpose of this particular study, and indeed other WMD issues in North Korea, will be reliant on the availability of open source or commercially available satellite-based sensors. Some analysts are confident that this technology will follow the trend of other space-based sensors, with technological developments allowing these capabilities to become more accessible to those outside governments.¹²⁵ Indeed, commercial providers such as Planet¹²⁶ and Orbital Sidekick¹²⁷ are hoping to launch hyperspectral sensors within the coming years.

In the context of this work, the use of hyperspectral imagery could help to identify the types of chemicals being used, the gas emissions and waste that result from the processes, and any leakage. Not only would this help inform understanding of the specific chemical processes taking place within buildings, but it could also provide an indication as to the quality and robustness of the site – are emissions emanating from intentional venting systems, or are leaks occurring? Because of its infancy, any initial use will likely be resource intensive and exploratory.

119. Adam Keith, 'Is Hyperspectral the Next Earth Observation Frontier?', *Space News*, 30 March 2019.

120. Hanham and Lewis, 'Remote Sensing Analysis for Arms Control and Disarmament Verification'.

121. US Geological Survey, 'USGS EROS Archive – Earth Observing One (EO-1) – Hyperion', 17 April 2019, <https://www.usgs.gov/centers/eros/science/usgs-eros-archive-earth-observing-one-eo-1-hyperion?qt-science_center_objects=0#qt-science_center_objects>, accessed 26 October 2021.

122. Liu et al., 'Eyes on U'.

123. Gary Borstad et al., 'Satellite Hyperspectral Imaging in Support of Nuclear Safeguards Monitoring', Institute of Nuclear Materials Management Symposium, Phoenix, Arizona, July 2004.

124. R Scott Kemp, 'Environmental Detection of Clandestine Nuclear Weapon Programs', *Annual Review of Earth and Planetary Sciences* (Vol. 44, June 2016).

125. Hanham and Lewis, 'Remote Sensing Analysis for Arms Control and Disarmament Verification'.

126. Robbie Schingler, 'Carbon Mapper Launches Satellite Program to Pinpoint Methane and CO2 Super Emitters', Planet, 15 April 2021, <<https://www.planet.com/pulse/carbon-mapper-launches-satellite-program-to-pinpoint-methane-and-co2-super-emitters/>>, accessed 26 October 2021.

127. Orbital Sidekick, <<https://orbitalsidekick.com/>>, accessed 26 October 2021.

Tentative Conclusions and Pathways for Further Research

THIS PAPER'S FEASIBILITY study explored the applicability of open source research and remote sensing to better understand North Korea's CW capability. Although remote sensing and open source research of this kind has been applied to understanding North Korea's nuclear weapons programme, there has been little effort to explore these tools in the context of a CW capability. Yet, a CW programme remains a concern for the international community.

Through a case study approach, the authors used open source research to gather data about one chemical industrial site in North Korea previously highlighted by several sources as being potentially involved in chemical agent production. Based on this data, the authors identified where the CW risks are and how remote sensing tools could be used to bolster their analysis.

This feasibility study indicates that there is utility in continuing to explore open source research and remote sensing to assess North Korea's CW capability. Using varying and complementary remote sensing tools will allow the mapping of multiple signatures across the whole chemical production process. This introduces the possibility of assessing the likelihood of particular hypotheses about the complex and its activities when all observables are grouped together. Taking such an approach can contribute to the understanding of dependencies between buildings, for example, and help to identify activity correlation across the site.

The authors have identified a number of next steps for this research:

1. Mapping out the chemical process flows identified as part of this study onto the Namhung complex would be a logical next step. Optical imagery will be beneficial, and developing an understanding of how chemicals might move around the complex, or be stored or transported elsewhere, may offer additional insight. Furthermore, testing the practical application of infrared and hyperspectral imagery will be important in taking this work forward. Drawing on a multi-disciplinary team of experts will be an important factor in testing and implementing these tools and analysing and understanding the data that can be gathered from these sensors. Furthermore, for hyperspectral analysis, there will be a waiting game to play until commercial providers are able to launch these sensors. In the meantime, work can be undertaken to use optical imagery to identify physical features of buildings and infrastructure to support an understanding of the site.
2. This approach should be replicated across North Korea's chemical industry, especially for chemical sites with credible past reports suggesting they play a role in CW production, such as those at Hamhung and Suncheon.¹²⁸ Assessments of more individual sites would

128. MND, 'Defense White Paper', 1990.

be used to support analytical judgements about the role North Korea's chemical industry could have in potential CW activities and would provide data to analyse how this infrastructure might be used to support a CW programme.

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

Taking this work forward and expanding beyond the feasibility study will be resource intensive; purchasing commercial imagery across a range of sensors is expensive, and new hyperspectral capabilities will also likely be very costly when they first come online. Analysing and mapping the results together will be time consuming, and will require a mix of expertise on North Korea, technical knowledge on CW programmes, chemical engineering and plant operations, and significant imagery processing and analysis experience. With this expertise, working on such a project full time, the authors estimate that significant progress on mapping North Korea's chemical industry in this way could be made within three years. Furthermore, this feasibility study selected a case study that has ample available information. The authors acknowledge that this level of information might not be comparable across all sites of interest.

Yet, replicating this approach across more chemical sites in North Korea could provide a valuable and unique insight into the country's CW capability. Expanding and fully implementing this approach will contribute to understanding of North Korea's CW capability, where the potential for agent (and type of agent) production within the country might be, and provide insight into the role the chemical industry might play in a CW programme and how active that weapons programme might be. It can help the development of both a series of scenarios on where the current risks might lie and credible hypotheses about the nature, shape and scope of a North Korean offensive CW programme. Using open source and commercially available information to do this allows the authors' analysis to be transparent and auditable, thus enabling more opportunities for international debate on this topic, especially in relation to plugging knowledge gaps, understanding where the challenges might be and working collaboratively to develop solutions.

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