



ASMES - 2025

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The Management and Utilization of Industrial Explosives Worldwide and in Vietnam: Achievements, Opportunities, Challenges, and Future Development Directions

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ABSTRACT

Industrial explosives play a crucial role in the mining, construction, transportation, and hydropower sectors. In recent years, both globally and in Vietnam, the management and utilization of industrial explosives have achieved significant progress, with legal frameworks and technical regulations increasingly being refined. These advancements have contributed to improving production efficiency while ensuring safety and security during their application. However, alongside these substantial benefits, blasting activities still face numerous challenges, such as persistent safety risks, inconsistent compliance with regulations across enterprises, and rising technological requirements in the context of digital transformation and sustainable development. On this basis, the paper analyzes and evaluates the current status, challenges, and opportunities in the management and use of industrial explosives in several countries worldwide and in Vietnam, thereby proposing strategic directions to strengthen the adoption of modern technologies, enhance specialized human resource training, and develop a safe and intelligent management system for industrial explosives that meets future socio-economic development requirements.

Keywords: Drilling and blasting, Industrial explosives, Mining, Sustainable development.

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1. Introduction

Industrial explosives (IEs) play a vital role in the mining, construction, transportation, and hydropower sectors. At present, the use and management of IEs in developed countries worldwide reveal a common trend: while expanding their scope of application to meet increasing demands in mineral extraction, construction, and infrastructure development, regulatory systems are being tightened to ensure safety and security [1, 2]. In Vietnam, the management and utilization of IEs in recent years have achieved notable progress, with legal documents and technical standards increasingly refined, thereby enhancing production efficiency and ensuring safety and security during use. Nevertheless, alongside these considerable benefits, blasting operations still face multiple challenges, such as high safety risks, inconsistent compliance with regulations among enterprises, and heightened technological requirements in the context of digital transformation and sustainable development. Against this backdrop, the paper analyzes and evaluates the current status of IE management and utilization in selected countries and in Vietnam, and subsequently proposes strategic directions to strengthen the adoption of modern technologies, enhance specialized human resource training, and establish safe and intelligent management systems for industrial explosives to meet future socio-economic development needs.

2. Current Status of Industrial Explosives Management and Utilization in Vietnam and Worldwide

2.1. Worldwide

According to MRFR analysis, the global explosives market for mineral extraction was valued at approximately USD 7.6–7.8 billion in 2022, reaching USD 10,944.95 million in 2023, and is projected to hit USD 19,752.55 million by 2032, with a compound annual growth rate (CAGR) of 6.78% between 2024 and 2032. This growth is primarily driven by increasing metal mining activities and the rising demand for coal, which currently accounts for 30% of global energy consumption. Major coal-producing countries include China, the United States, the United Kingdom, Germany, Canada, India, Indonesia, and South Africa, with China alone representing 50% of global coal demand. Industrial explosives such as ANFO, emulsions, and water-gel/slurry explosives constitute the majority of industry revenues. Demand is also expanding for military applications and tunnel construction. Strategic partnerships and technological advancements are shaping the future of the explosives sector, with a strong emphasis on safety and environmental sustainability.

a) United States

The United States is among the world's largest producers and consumers of industrial explosives. According to U.S. Geological Survey (USGS) data, the annual demand for explosives is around 5–6 million tonnes, mainly serving coal mining in Wyoming and Virginia, as well as metal mining in Nevada and Arizona [9, 10]. ANFO dominates consumption, accounting for over 80% of total usage due to its low cost, ease of production, and high efficiency in surface mining. Emulsions and water-gel explosives are also widely applied in underground operations and water-bearing rock conditions.

The U.S. is a major producer of ammonium nitrate, both for domestic use and export to Canada, Mexico, and South American countries. In 2024, the U.S. explosives market was valued at USD 2.83 billion, representing nearly 40% of North America's revenue. The industry creates more than 60,000 direct and indirect jobs, contributes over USD 19 billion to GDP annually, and

generates about USD 1.2 billion in federal tax revenues, in addition to over USD 1 billion in state and local taxes.

The U.S. regulatory framework combines federal law with administrative regulations enforced by the Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF), covering licensing, storage, transportation, and theft reporting. In mining operations, the Mine Safety and Health Administration (MSHA) is responsible for accident data collection and enforcing its own safety standards [11].

b) Canada

Canada has a highly developed mining industry, especially in gold, nickel, copper, and uranium extraction, which drives significant explosives demand. ANFO and emulsions are the main products, with emulsions being used more frequently than in the U.S. due to the challenges of using dry ANFO in cold climates. Canada imports part of its ammonium nitrate supply from the U.S. and Europe, while exporting finished explosives to South America [9, 12].

In 2024, the Canadian explosives market generated approximately USD 430 million in revenue, with a projected CAGR of 4.2% in the coming years [9, 12]. Demand for explosives is expected to rise substantially by 2035 as advanced blasting technologies are increasingly adopted. Canada enforces strict regulations on explosive precursors, including ammonium nitrate ($\geq 28\%$ N), hydrogen peroxide ($\geq 30\%$), and nitromethane. Oversight of imports, production, distribution, and usage, including fireworks, falls under the jurisdiction of Natural Resources Canada's Explosives Regulatory Division (ERD). Before approval, every explosive or related device must undergo classification and licensing procedures in line with applicable laws and policies. Canada regularly updates precursor lists and collaborates with customs and police authorities to monitor sensitive imports.

c) Australia

Australia is among the largest producers and consumers of explosives in the Asia-Pacific, primarily serving coal and iron ore mining. Corporations such as Orica and Dyno Nobel both manufacture domestically and export to Indonesia, Papua New Guinea, and Africa [14, 15]. ANFO remains the dominant product, although emulsion explosives are rapidly gaining market share due to their superior safety characteristics. Electronic detonator systems are widely deployed to optimize blasting performance.

The Australian explosives sector generated about USD 4.6 billion in revenue in 2025, with steady growth at a CAGR of 2.1% [9]. Australia emphasizes safety-enhancing technologies, including digital systems and automation in blast design, initiation, and monitoring. Modern electronic detonators equipped with microchips enable precise programming of delay intervals down to milliseconds, or even 0.1 ms [14]. This state-of-the-art technology is gradually replacing conventional electric and non-electric detonators in mining and construction. Mines increasingly rely on site-mixed emulsions to improve safety and reduce risk. Dyno Nobel prioritizes emissions reduction, safer transport and production practices, and balancing safety with sustainability.

The federal government plays a key role in policy and regulatory frameworks concerning occupational health, safety, and welfare, and establishes general safety principles for working with explosives.

d) Germany

Germany represents a medium-sized market in Europe, with stable explosives production and consumption. Management is strictly aligned with EU environmental and safety

standards, while advanced technologies are actively promoted. In response to defense requirements, the sector has been expanding significantly under the EU's defense capacity-building programs. In 2024, Germany's explosives market was valued at approximately USD 532 million, with a forecasted CAGR of 3.9% [9]. According to Grand View Research, explosives for research applications alone reached USD 387 million and are expected to rise to USD 473 million by 2030.

Germany emphasizes safe and environmentally friendly blasting technologies. The sector is tightly regulated, particularly regarding licensing, safety and environmental controls, precursor classification, and anti-terrorism measures. Overall, Germany maintains one of the strictest and most comprehensive explosives regulatory systems worldwide, with a focus on safety, security, and sustainability, closely integrated with EU law.

e) China

China is the world's largest producer and consumer of industrial explosives, with production exceeding 4.6 million tonnes in 2023, accounting for about 52% of global output [9, 17]. The market serves coal, iron ore, and metal mining, as well as infrastructure, hydropower, and tunneling projects. In 2024, China produced about 1.3 million tonnes of packaged explosives, maintaining steady growth at an average annual rate of 4.5% from 2013 to 2024. Imports in 2024 totaled only 3 tonnes (about USD 11,000), reflecting a sharp decline after two years of growth, with the U.S. as the primary supplier. Exports reached 2,300 tonnes (USD 15 million), down 56% from previous years, mainly destined for Australia (1,500 tonnes), Myanmar, and Nepal.

Looking forward, China's explosives market is projected to increase by 1.4 million tonnes in volume and reach USD 6.6 billion in value by 2035. The industry is centrally regulated, with a dedicated administrative framework. China maintains an official "Catalogue of Approved Industrial Explosives," clearly defining permissible and prohibited activities, while frequently updating precursor and restricted material lists.

2.2. Vietnam

2.2.1. Current status of industrial explosives management

Vietnam is witnessing robust growth in its industrial explosives sector, with steady increases in both production and export. As a country with an expanding mining industry and rapid development in construction and transportation projects, particularly in coal, bauxite, copper, iron, and other mineral extraction, the demand for industrial explosives has been rising significantly. At present, ANFO and emulsion explosives are the dominant types, widely applied in surface mining depending on geological, climatic, and technical conditions [1, 2].

Nationwide, nine enterprises are officially licensed to manufacture and trade industrial explosives and explosive precursors, operating a total of 59 production lines. If operated continuously in three shifts, these lines could achieve an annual capacity of nearly 300,000 tonnes, whereas domestic demand is estimated at about 120,000–160,000 tonnes per year. In 2024, Vietnam's industrial explosives production included: 148,165 tonnes of various explosives, 40.87 million detonators, 2,439 tonnes of blasting caps/primers, 12.7 million meters of detonating cord and safety fuse, and 2,957 tonnes of high explosives. Additional products such as perforating charges, detonating cords, and blasting caps for oil and gas exploration have also been developed and tested with positive results [6, 7].

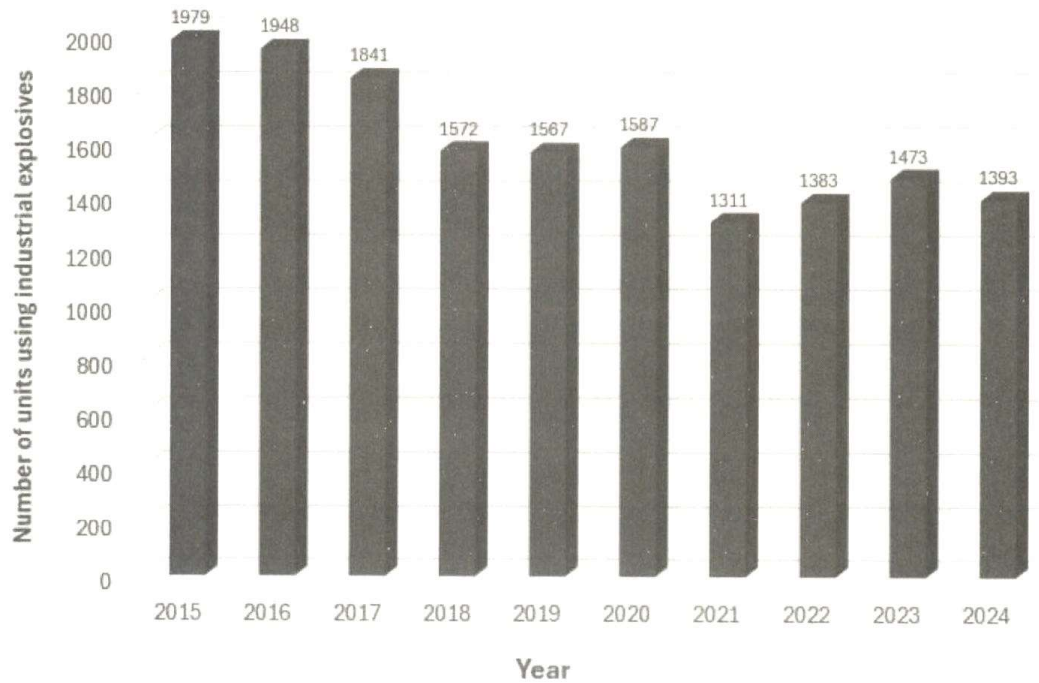


Figure 1. Industrial explosives consumption demand in Vietnam over the years

The structure of IEs production in Vietnam is relatively diverse in terms of product types. Coal mining accounts for approximately 55% of consumption, stone and construction material extraction together with civil engineering projects account for about 35%, and cement production represents roughly 10%. By product category, ANFO explosives make up around 55%, emulsion explosives about 33%, AD1 explosives approximately 8%, TNT-free powder explosives about 4%, and other types of explosives about 5%. At present, AD1 production is gradually declining and being replaced by TNT-free powder explosives.

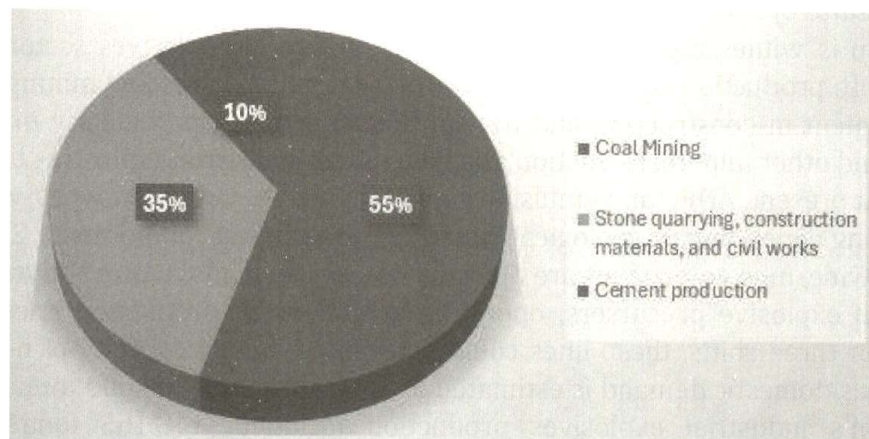


Figure 2. Structure of industrial explosives production by end-use sectors in Vietnam

2.2.2. Current status of industrial explosives utilization

Under Vietnamese regulations, seven explosive precursors are permitted for industrial explosives (IEs) production: ammonium nitrate (NH_4NO_3), sodium nitrate

(NaNO_3), nitromethane (CH_3NO_2), potassium nitrate (KNO_3), sodium chlorate (NaClO_3), potassium chlorate (KClO_3), and potassium perchlorate (KClO_4). Two of these, ammonium nitrate (NH_4NO_3) and sodium nitrate (NaNO_3), are already manufactured domestically: (i) a 20,000 t/y ammonium nitrate production line in Vinh Phuc operated by Company 95 under the Ministry of National Defense; (ii) a 200,000 t/y ammonium nitrate plant in Thai Binh; and (iii) a 2,000 t/y sodium nitrate pilot line in Uong Bi, Quang Ninh, both owned by the Mining Chemical Industry Corporation – Vinacomin (MICCO) of Vietnam National Coal and Mineral Industries Group (VINACOMIN/TKV). MICCO plans to invest in an ammonia (NH_3) production line integrated with the 200,000 t/y ammonium nitrate facility to synchronize inputs for ammonium and sodium nitrate production and thereby mitigate the significant risks and costs currently associated with transporting and storing ammonia during logistics operations.

For sodium nitrate (NaNO_3) as an explosive precursor, MICCO's pilot line at Hong Thai Tay Ward, Uong Bi City, with a capacity of 2,000 t/y, already meets domestic demand for emulsion explosive manufacture ($\approx 1,800$ t/y). Other sectors require roughly an additional 3,000 t/y; at present, about 3,000 t of NaNO_3 are imported annually, primarily from China. Under the Prime Minister's Decision No. 726/QĐ-TTg dated 16 June 2022 on orientations for explosive-precursor production to 2030, "Maintain stable ammonium nitrate production; invest in other explosive precursors that are dual-use chemicals meeting the needs of other industrial production and fertilizers", enterprises should consider appropriate investment portfolios for selected precursors. Emulsifiers, complex waxes, and related inputs for emulsion explosives are currently 100% imported due to the absence of domestic production.

Regarding IEs trading, two enterprises are licensed: MICCO (VINACOMIN/TKV) and the General Agency for Engineering and Technology (GAET). Vietnam's IE products are exported to several countries, including Laos, Poland, and Ethiopia, with Poland being one of the major markets. These companies have developed extensive, integrated nationwide supply networks, invested in compliant storage facilities and dedicated transport equipment, and trained personnel to required professional standards. They are able to supply IEs to users at distribution depots or directly to project sites and, to date, have avoided supply-chain accidents or losses that could affect public security and safety. Currently, imports are limited to certain IEs used in oil and gas exploration and production under entrusted contracts with petroleum contractors; selected explosive accessories required by some construction contractors; and explosive ingredients not yet manufactured domestically (e.g., TEN, Hexogel, etc.).

In 2023, MICCO recorded more than USD 77 million in IEs export revenue, up 168% year-on-year. In 2024, MICCO produced 161,100 t of ammonium nitrate and sold 6,500 t to Australian customers, maintaining growth momentum (126% versus the same period). For 2025, MICCO plans to produce 190,000 t and export 2,500 t of ammonium nitrate to Cambodia [6]. Factories under the General Department of National Defense Industry (Z113, Z121, Z131, Z114, Z115) manufacture explosives, ammunition, and military equipment; notably, Z113 exported equipment worth nearly USD 1 billion in 2024.

Regulatory management of IEs. Vietnam's IEs management is strictly regulated and implemented through a comprehensive legal corpus, including legislation governing the management and use of weapons, industrial explosives, and supporting tools [3, 4, 5, 8];

regulations under the Ministry of Industry and Trade (MOIT) on the management and use of IEs and explosive precursors for IEs production; safety requirements for the manufacture, testing, acceptance, storage, transport, use, and disposal of IEs, and the storage of precursors; and administrative-sanction provisions in the chemicals and IEs domain. To enhance enforcement effectiveness, the Department of Industrial Safety and Environmental Protection (MOIT) has coordinated with the Department of Administrative Management of Social Order (Ministry of Public Security) to intensify dissemination and guidance on new legal provisions to agencies, organizations, and enterprises active in this field. Nevertheless, statistics from the Department of Occupational Safety (Ministry of Labour–Invalids and Social Affairs) indicate that safety incidents related to IEs management and use remain complex: serious accidents have occurred; theft and loss still happen; and common violations are concentrated in supply, inventory accounting, import–export procedures, and safeguards against diversion of IEs. It is therefore necessary to objectively and rigorously review IEs management from central to local levels, assess compliance with the legal framework, and evaluate the implications of IEs activities for public security, occupational safety, and social order.

2.2.3. Opportunities and challenges in the management and utilization of industrial explosives

2.2.3.1. Opportunities

a) Growing demand for industrial explosives in the coming years

Amid the green-energy transition, the shift from fossil fuels to clean energy has moved beyond a recommended trend to an urgent, compulsory requirement under global climate change. Within this context, open-pit mining will play a pivotal role in economic development, contributing significantly to GDP and state budget revenues, and serving as a key to sustainable development, efficient resource utilization, and Vietnam's gradual entry into the green-energy industrial era. Rising demand for construction materials, mineral extraction, transport infrastructure, renewable energy, hydropower, and thermal power is expanding the explosives market for large-scale projects and will require substantial IE supply in the near future.

b) A progressively more complete legal–regulatory framework

Economic policy instruments, such as the Law on Geology and Minerals, the Law on Environmental Protection, the Law on Enterprises, and related sub-law documents, have created an enabling legal corridor that encourages open-pit mining enterprises to expand, invest, and partner domestically and internationally, thereby scaling up operations and improving business efficiency.

In parallel, the corpus of laws on the management and use of weapons, industrial explosives, and supporting tools, together with implementing decrees and circulars, has simplified procedures, strengthened oversight, and increased transparency across licensing, importation, manufacturing, and distribution. The body of regulations governing IE activities and explosive precursors is now more complete, coherent, and implementable, providing a crucial legal foundation for orderly IEs operations and contributing to national socio-economic development.

c) Adoption of advanced technologies in IE management and use

A key avenue to improve blasting performance is to raise drilling effectiveness by investing decisively in modern drilling technologies and equipment, an urgent requirement at open-pit coal mines. At present, most open-pit coal mines employ rotary drills such as

SBSH-250 and XBS-250MN (Russia) and DML-1600 and DM-45LP (Ingersoll Rand) with diameters of 200–250 mm; hydraulic rotary drills such as CAT MD6250 (USA); and down-the-hole/rotary-percussion rigs such as PANTERA-1100, PANTERA-1500, and TITON-500 (Tamrock), and CM-115 and CM-117 (Atlas Copco) with diameters of 100–175 mm for drilling-blasting operations. These rigs feature data connectivity, software/firmware updates for monitoring operating-hour parameters, and automatic adjustment of drilling modes; they are fuel-efficient and maneuverable on deep pit benches to meet production targets and sustain sectoral growth.

Mines prioritize high-energy explosives and water-resistant formulations for wet holes, while favoring cost-effective products to replace higher-priced types. Blast-hole layout, charge configuration, drilling-blasting parameters, and initiation systems are selected to suit site conditions, including non-electric millisecond delays, hole-by-hole full-delay blasting, and pre-split/contour blasting. High-bench blasting is preferred to increase column-charge height ratios and thereby reduce drilling costs. Charging operations at surface mines have been modernized with specialized bulk charging equipment to shorten cycle times and raise labor productivity [1, 2].

Open-pit mines have also deployed software for preparing blast designs (“passports”), accelerating planning with fast and accurate outputs that enhance fragmentation performance. In recent years, new instrumentation aligned with Industry 4.0 has been introduced in Vietnam for monitoring blast impacts on protected structures, including the Bartec Syscom MR3000BLA blasting-monitoring system (Switzerland), the Sigicom INFRA C22 wireless vibration monitor (Sweden), and Real-Time Wireless Sensors for blasting vibration (Korea). Research on AI-based models to predict blast-induced ground vibration has been implemented at surface mines using IEs; results demonstrate improved predictive accuracy and help mitigate environmental impacts. Given that blasting generates substantial dust and air pollution, deepening surface mines have also adopted technologies and devices for ambient air-quality monitoring and control to protect workers’ health, enhance operational efficiency and safety for personnel and equipment, and support the sustainable development of Vietnam’s coal industry.

d) Enhanced training quality, scientific research, and international cooperation

As open-pit mining advances toward modernization, automation, and sustainability, the roles of mining engineers and IEs specialists have become increasingly critical. Accordingly, training must align with new trends, integrating theory, field practice, and advanced technologies. Leveraging strong infrastructure and experienced faculty at the Hanoi University of Mining and Geology, the curriculum offers a broad scientific foundation in IEs applications. Students engage in extensive hands-on activities and industry placements, building a cohort of IEs engineers meeting international standards and the sustainability requirements of the mining sector in the Industry 4.0 era.

Universities and enterprises in Vietnam, such as MICCO and GAET, are also expanding international collaboration in research, production, and export of explosives and precursors. Access to state-of-the-art technologies from global corporations further enhances efficiency and safety in IEs utilization.

2.2.3.2. Challenges

a) Technological development challenges

With rapid advances in automation, robotics, artificial intelligence (AI), remote monitoring, and the Internet of Things (IoT), smart drilling–blasting technologies are reshaping traditional practices in Vietnam. Open-pit mining engineers must not only master fundamental drilling and blasting principles but also be proficient with blast-design software (e.g., BlastDesign, JKSImBlast, SHOTPlus, O-Pitblast), numerical modeling, and big-data analytics to optimize operations. In parallel, adoption of modern industrial explosives (IEs), such as electronic millisecond detonator systems, energy-concentrating sleeves/tubes, and high-energy, environmentally friendly formulations, has become imperative.

b) Heightened safety and environmental challenges in IEs use

Domestic and international standards are increasingly stringent regarding control of blast-induced ground vibration, airblast overpressure, flyrock, noise, dust, and toxic fumes. This requires open-pit engineers to apply AI-based predictive models prior to execution and to implement effective mitigation measures. The trend toward “green,” low-emission mining compels continuous innovation to ensure operations are both efficient and sustainable.

c) Legal and management challenges for IEs

Amid global integration, regulations governing the manufacture, transport, storage, and use of IEs are becoming tighter. To develop Vietnam’s IEs industry along a sustainable, advanced, and low-impact pathway, it is essential to reaffirm the sector’s critical role in economic development, national security and defense, and public order. Open-pit engineers must strengthen their understanding of legal requirements and international standards to ensure compliance.

Adopting a professional, closed-loop IEs supply and use model, from mine design, blast-impact assessment, and environmental impact assessment to transport, storage, and blasting execution, as practiced by entities such as MICCO and GAET, helps reduce occupational risks and safeguard security and social order. In addition, “smart magazines” with remote monitoring, safety alarms, and IoT integration are becoming a common requirement. State management mechanisms and policies should be refined and codified to create a comprehensive, systematic legal framework for sustainable development and governance of the IEs sector. To work with international mining corporations, Vietnamese engineers will also need relevant professional certifications and the ability to participate in modern governance processes.

d) Workforce and cross-disciplinary skills challenges

Future Vietnamese open-pit engineers must go beyond mining and blasting knowledge to develop cross-/multi-disciplinary competencies. Required capabilities include GIS, 3D modeling, LiDAR and laser scanning, as well as numerical simulation tools such as CFD (Computational Fluid Dynamics) and FEM (Finite Element Method) for assessing blast impacts. Project management, risk assessment, and safety management aligned with international standards are also essential. Specialized technical English proficiency is particularly critical for accessing new knowledge and integrating into the global labor market.

e) Challenges arising from sustainability requirements

Open-pit mining is shifting decisively toward smart and green paradigms to reduce greenhouse-gas emissions, limit ecosystem impacts, and improve resource efficiency. Engineers must ensure reductions in CO₂ and NO_x emissions from explosive use while