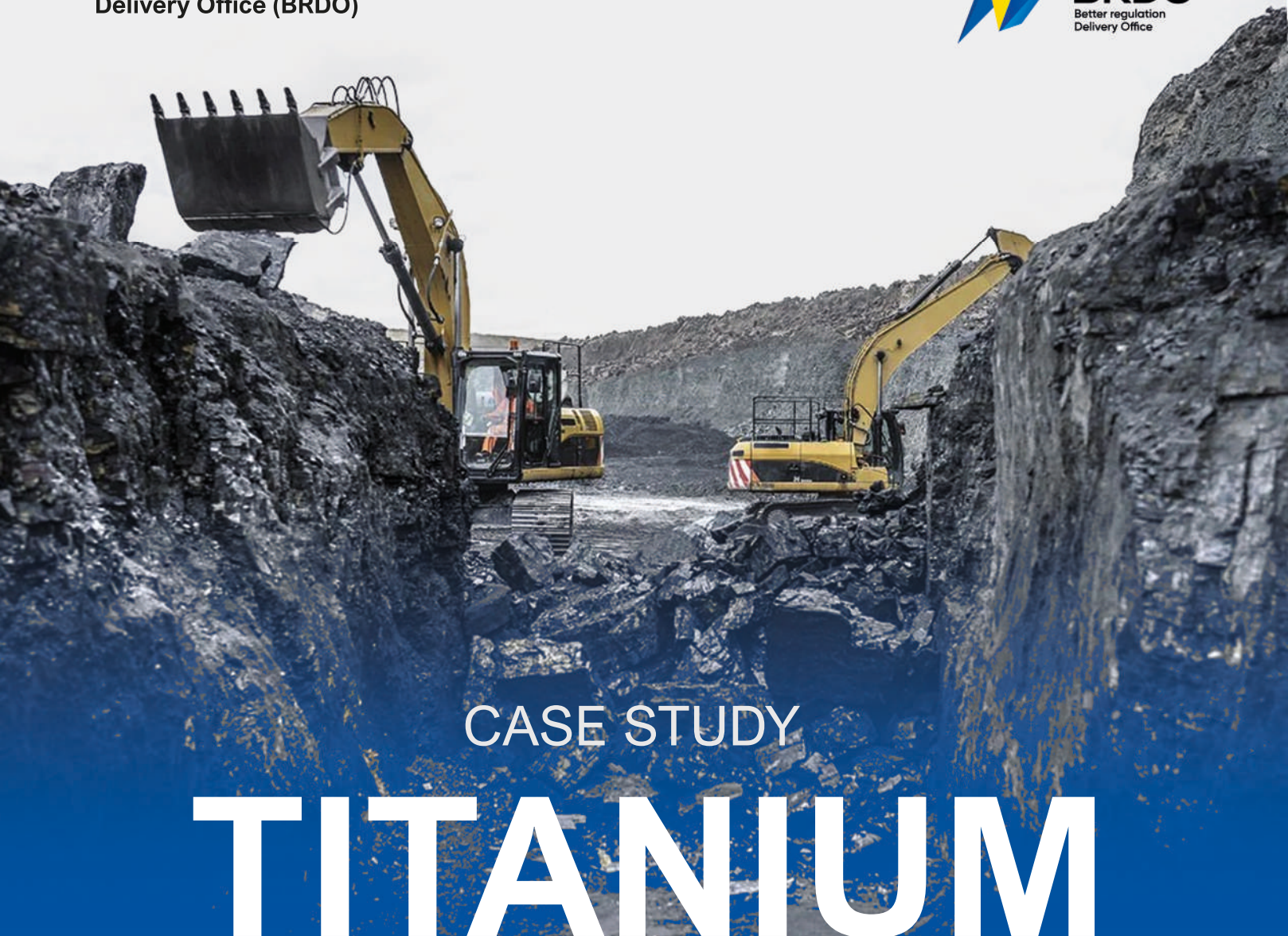




CASE STUDY

TITANIUM

From Ore to Innovation:
a comprehensive analysis of the titanium industry
in the context of Ukrainian industrial policy

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INTRODUCTION

Titanium is a strategic material in modern industry. Its combination of high strength, biocompatibility, corrosion resistance and relatively low density makes this metal indispensable in leading high-technology sectors — aerospace, defence, medical and chemical.

The growth of the global aircraft fleet, advances in additive manufacturing and medical technologies are increasing demand for titanium and titanium alloys. At the same time, geopolitical and environmental challenges bring into focus the resilience of supply chains and the adoption of innovative technologies.

The aim of this study is to develop an integrated view of the current status and future prospects of both the global and Ukrainian titanium markets, to establish strategic priorities for industrial policy and business strategies, and to provide recommendations for optimising the value-chain of added value creation.

The objectives of the research include:

- analysing the extraction of ilmenite and rutile;
- assessing technologies for the production of titanium sponge and titanium dioxide;
- investigating the structure of global demand for metallic titanium;
- examining Ukraine's resource base, production capacity and export potential.

The methodology combines quantitative and qualitative approaches. The quantitative analysis is based on statistics from USGS, the World Bank and ACI World, as well as econometric models to estimate multiplier effects. The qualitative component includes expert interviews, analysis of legal and regulatory acts (in particular the Critical Raw Materials Act and the Horizon Europe programme), and a review of international practices in supply-chain digitalisation.

Furthermore, an analysis of global trends in the context of Ukraine is undertaken, along with recommendations for modernising production, developing digital solutions, and increasing export potential. The structure of the study covers the entire chain — from raw materials to end products — demonstrating the industry's development prospects in the face of global challenges.



SECTION 1. OVERVIEW OF THE GLOBAL TITANIUM MARKET

Titanium is a lightweight yet strong metal whose corrosion resistance and unique physico-chemical properties make it a principal material in high-technology sectors. Its applications encompass aerospace and space engineering, medicine, defence industries, and chemical production.

Industrial use of titanium began in the 1940s in the United States following the introduction of the Kroll process, which enabled production of the metal at industrial scale.

The global development of the titanium industry is closely linked to the aerospace sector. According to ACI World, the volumes of global air transportation grow at an average of 5–6% annually, driving demand for lightweight and durable materials, particularly titanium alloys.

In response, leading producers are expanding raw-material extraction and upgrading capacities for titanium sponge production.

Within this section, the key elements of the value-addition chain are examined:

- extraction and beneficiation of titanium ores (1.1);
- production of titanium sponge (1.2);
- global consumption of metallic titanium (1.3);
- trends in the titanium dioxide market as an intermediate product (1.4).

This approach allows a comprehensive assessment of both production and consumption aspects, as well as the identification of strategic risks and opportunities. Particular attention is paid to environmental and geopolitical factors that shape market resilience and its development prospects.



1.1. GLOBAL PRODUCTION OF TITANIUM ORES

The principal sources of titanium are **ilmenite and rutile**. Ilmenite accounts for approximately **90% of global demand** for titanium minerals, while rutile—though less abundant—features a **high titanium dioxide content (over 85%)** and is used in the production of metallic titanium and titanium dioxide for specialised applications.

According to the U.S. Geological Survey (USGS), global ilmenite production in **2024** was approximately **8.9 million tonnes**, representing a **0.7% increase** over 2023 (8.84 million tonnes). In contrast, rutile production fell from **590 000 tonnes in 2023 to 450 000 tonnes in 2024** (a –24% change). These shifts are driven by both technological and geopolitical factors affecting the accessibility of individual deposits and the cost of extraction.

Global leaders in ilmenite production (2024):

- **China** — ~37% of global output (3.3 million tonnes)
- **Mozambique and South Africa** — together ~36% (1.9 and 1.3 million tonnes, respectively)
- **Canada** — around 4% (0.35 million tonnes)
- **India** — ~2% (0.21 million tonnes)
- **Senegal** — ~3% (0.3 million tonnes)

Leading producers of rutile (2024):

- **Australia** — 200 000 tonnes (~44% of global volume)
- **South Africa and Sierra Leone** — key producers, though Sierra Leone cut its output by nearly 46% in 2024

Regionally, over 60% of global production of titanium concentrates is located in the Asia-Pacific region, about 25% in Africa, and the remaining 10–15% across North and South America and Europe. In recent years, a clear trend toward supply diversification has emerged: new deposits are being developed in South America and Australia, while production capacities are being upgraded in South Africa and Mozambique.

The economic value of the global ilmenite market in 2024 was estimated at USD 11–12 billion. Forecasts suggest that by 2034, this could grow to USD 16.8 billion, with an average annual growth rate of approximately 4%. Demand is fuelled not only by the aerospace and defence sectors, but also by the production of titanium dioxide for the paint, plastics, and paper industries.

About 55% of titanium dioxide is used as a white pigment in paint manufacture, with the remainder used in plastics, paper, and specialist materials. Meanwhile, the aviation sector continues to be the primary consumer of metallic titanium, making the stability of ilmenite and rutile extraction strategically crucial.

Contemporary approaches to sustainable development emphasise reducing the environmental impact of beneficiation technologies and integrating social programmes in mining regions. However, geopolitical instability in several African and East Asian countries increases the risk of supply disruptions and price volatility, necessitating constant monitoring and diversification of supply chains.



1.2. PRODUCTION OF TITANIUM SPONGE

The manufacture of titanium sponge constitutes a pivotal stage in converting ore feedstock into metallic titanium suitable for the subsequent production of ingots and alloys. The dominant industrial method remains the **thermochemical Kroll process**.

This process involves the **chlorination of ilmenite or rutile** to form titanium tetrachloride (TiCl_4), followed by **reduction with magnesium** in an inert gas environment at **800–1000 °C**. As a result, a **porous titanium sponge** is produced, along with a by-product, magnesium chloride (MgCl_2), which is subject to within the production cycle.

Global Production.

Output of titanium sponge has risen from 114 000 tonnes in 2000 to 309 000 tonnes in 2024.

Global production breakdown (2024):

- China — 71 % ($\approx$ 220 000 tonnes)
- Japan — 17.8 % ($\approx$ 55 000 tonnes)
- Russia — 6.5 % ($\approx$ 20 000 tonnes)
- Kazakhstan — 4.5 % ($\approx$ 14 000 tonnes)
- Saudi Arabia — 4.9 % ($\approx$ 15 000 tonnes)

As of 2025, the United States has no commercial sponge production for metallurgy — its last plant ceased operation in 2020. However, per USGS-2024, a small facility in Salt Lake City produces approximately 500 tonnes per year, targeting electronic-grade material (US DOC, May 2025; USGS-2024).

Technological Aspects

- **Advantage of the Kroll process:** high degree of titanium purification.
- **Disadvantage:** considerable energy intensity — approximately 423 GJ per tonne; electricity accounts for over 60 % of total energy consumption (based on Chinese life-cycle analyses).
- **Economic benchmarks:**
Average sponge import price to the U.S. in 2023: ~US 12 USD/kg
Target price for HAMR-derived powders after scaling: ~US 5.5 USD/kg
Cost variations stem from differences in energy, feedstock, and labour expenses.

Product Quality

The aerospace industry demands sponge of the highest purity, with impurity levels (Fe, Si, Al) below 0.1 %, and conformance to AMS standards. Outside China, certified aerospace-grade sponge is supplied by Japan, Kazakhstan, and Saudi Arabia. Russia historically was a major supplier, but from 2022 to 2025 most deliveries to Western OEMs ceased due to sanctions and voluntary procurement restrictions. Chinese producers generally target industrial, lower-specification markets.

Innovations & Environmental Considerations

- **Energy efficiency:** Employing induction heating in reactors may reduce energy consumption by about 15 %.
- **Novel methods:** Research is underway into electrochemical reduction of TiCl_4 , with potential titanium yields up to 98 % and lower operating temperatures.
- **Sustainability:** Implementing closed loops for Mg and Cl recycling helps reduce emissions and operational costs.

Ukrainian Context

The Zaporizhzhia Titanium-Magnesium Plant (ZTMK) was designed for an annual capacity of 20 000 tonnes, but due to logistical challenges and its shutdown in 2022, actual production fell to zero. In that year, approximately 1 000 tonnes were sold from existing inventory. Revival of ZTMK would require technological upgrades, energy-efficiency improvements, and investment.

Prospects for Growth.

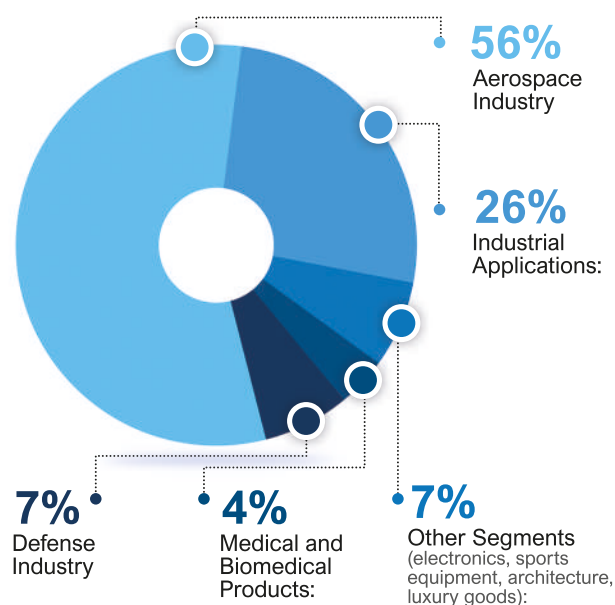
By 2030, global sponge production capacity could reach 400 000 tonnes per annum. Key demand drivers include:

- **Aerospace sector** (demand growth ~6 % annually)
- **Medical implants** (growth ~8 % annually)

To secure a stable supply chain, new production projects are being considered in **South America and Africa**, aiming to reduce dependence on the Asian market.

1.3. GLOBAL CONSUMPTION OF METALLIC TITANIUM BY INDUSTRY

The demand for metallic titanium is concentrated in several key economic sectors. In 2024, its distribution across industries was as follows:



Aerospace Sector: The primary consumer of titanium due to its high strength-to-weight ratio and corrosion resistance. In 2024, this sector consumed over 170,000 tonnes, accounting for more than half of global demand. Titanium is used in aircraft structures (fuselages, wings), aircraft engine components (compressor blades, casings), and spacecraft. Demand is directly tied to the growth of air travel: according to ACI World forecasts, global passenger traffic will exceed 9.9 billion in 2025, a 4.8% increase compared to 2024.

Industrial Applications: Approximately a quarter of global titanium is consumed by the chemical, petrochemical, oil, and gas industries. The metal is used in heat exchangers, reactors, pipelines, and other equipment operating in aggressive environments and at temperatures up to 600°C. Titanium's advantage lies in its durability and reduced maintenance costs. In 2024, this segment accounted for about 80,000 tonnes (26% of demand).

Defense Industry: This sector accounts for approximately 7% of consumption. Titanium is used in armored vehicles, submarine hulls, missile systems, and helicopters. Examples include its application in the F-35 Lightning program and modern submarine hulls. Demand is driven by government defense contracts and military modernization programs.

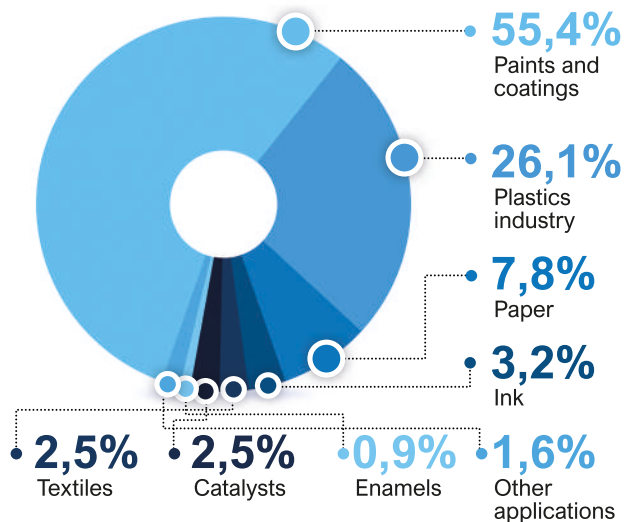
Medical Sector: Medical and biomedical products represent about 4% of demand. Due to its biocompatibility and lack of toxic impurities, titanium is widely used in orthopedic and dental implants, stents, and surgical instruments. This sector shows steady growth due to an aging population and advancements in medical technologies.

Other Segments: Approximately 7% of global demand comes from electronics, sports equipment, luxury goods (watches, jewelry), and architectural solutions. These segments are growing due to the combination of titanium's functionality and aesthetic properties.

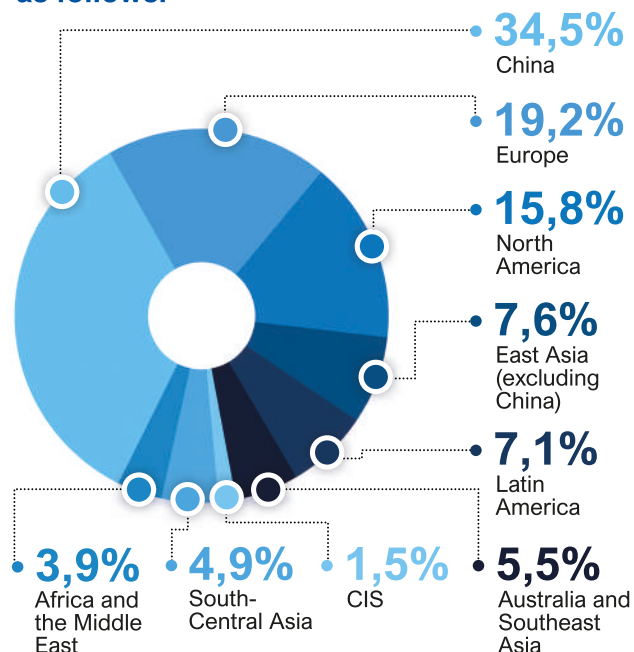
Conclusion: The aerospace and industrial sectors remain the primary drivers of titanium consumption, while the defense and medical sectors provide strategic and social significance. Favorable forecasts for all industries indicate stable demand in the medium term, creating a foundation for expanding production and investments.

1.4. TITANIUM DIOXIDE MARKET TRENDS

The consumption of titanium dioxide pigment by industrial sectors is presented as follows:



The consumption by regions is presented as follows:

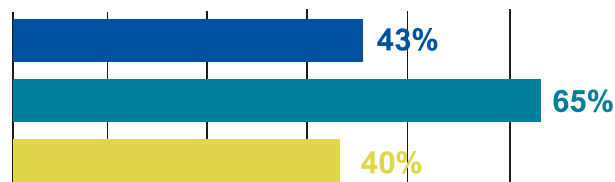


Key Producers:

- Chemours (USA): **16.4%** market share;
- Cristal (Saudi Arabia): **11.2%**;
- Venator (USA): **10.3%**;
- Lomon Billions (China): **9.3%**;
- Kronos (Germany): **7.5%**;
- Tronox (USA): **6.2%**.

Major consumers include companies like PPG, Sherwin-Williams, AkzoNobel, Nippon Paint, and Masco, which together account for about 40% of demand in the paint and coatings sector.

Key consumers:



■ Paints and coatings: Sherwin-Williams, PPG, AkzoNobel, RPM, Axalta, Nippon Paint, BASF, Kansai Paint, Jotun, Masco. Together, these companies account for 43% of this market.

■ Printing inks: DIC/Sun, Flint Group, Toyo Ink, Sakata, Siegwark. Together, these companies account for 65% of this market.

■ Plastic masterbatch: Ampacet, Cabot, Clariant, Dainichiseika, Inabata, PoluOne, Schulman. Together, these companies account for 40% of this market.

Titanium dioxide (TiO₂) is a key intermediate product in the titanium industry, primarily used as a white pigment. Its production is carried out using two methods:

• **Sulfate Process:** Involves treating ilmenite or titanium slag with concentrated sulfuric acid, followed by hydrolysis and calcination of precipitated TiO₂. Advantage: ability to use lower-quality ores and relatively low capital costs. Disadvantage: generation of large volumes of waste requiring complex storage.

• **Chloride Process:** Involves chlorination of high-quality raw materials (rutile or enriched ilmenite) to produce TiCl₄, which is then oxidized at around 1000°C in fluidized bed reactors. This method ensures a high-purity, glossy product but requires more expensive raw materials and strict technological control.



Market Trends:

- In 2024, the TiO_2 market produced via the chloride process was valued at USD 5.2 billion. From 2026 to 2033, it is expected to grow at a rate of 5% per year.
- The paint and coatings industry consumes about 60% of TiO_2 , plastics 20%, the paper industry 5%, and other sectors (cosmetics, food industry, ceramics, catalysts) collectively account for 15%.
- The largest regional market is the Asia-Pacific region (over 40% of global demand). Europe accounts for about 20%, North America 25%. Latin America, the Middle East, and Africa collectively contribute about 15% of demand, showing the highest growth rates due to large infrastructure projects.

Environmental Aspects:

- The sulfate process generates significant volumes of gypsum waste, limiting its use under strict environmental regulations.
- The chloride process, despite higher capital intensity, is considered more promising due to the ability to recycle by-products and reduce environmental impact.

Conclusion:

The titanium dioxide market is undergoing structural transformation: the share of the chloride process is growing, competition between Western and Chinese producers is intensifying, and environmental standards are shaping technological priorities. This directly impacts Ukraine's position, where modernization of production facilities and adoption of cleaner technologies could be key to accessing global markets.

CONCLUSION TO SECTION 1

Analysis of the global titanium market confirms its strategic importance for high-tech industries. Ilmenite and rutile mining generally show stable growth, with the majority concentrated in the Asia-Pacific region and Africa (together over 80% of global production). Uneven resource distribution and dependence on politically unstable regions create risks for stable supply.

Titanium sponge production continues to rely on the Kroll process. Its advantage is high metal purity, but its drawback is significant energy intensity and environmental challenges. Innovations in reagent recycling, induction heating, and electrochemical methods could potentially reduce costs and emissions.

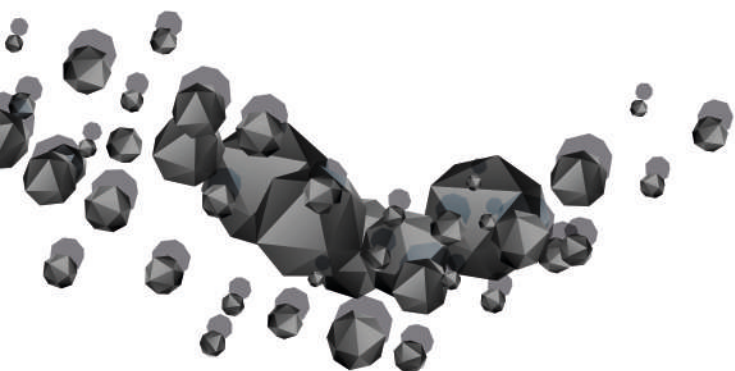
Titanium consumption is concentrated in two sectors— aerospace and industrial— which together account for over 80% of demand. The defense and medical sectors hold strategic importance and reinforce the need for reliable and stable supply chains.

The titanium dioxide market is developing through two technologies— sulfate and chloride. The gradual increase in the chloride process share is driven by quality requirements and environmental standards. The Asia-Pacific region remains the leader in consumption and production, while Europe strengthens regulatory oversight, and North America maintains high quality standards.

Global trends highlight several key development directions:

- Diversification of raw material sources to reduce supply chain risks;
- Investments in energy-efficient and environmentally friendly technologies;
- Integration of digital solutions and monitoring systems to enhance supply chain transparency;
- Development of additive manufacturing as a new driver of demand.

For Ukraine, these findings underscore the need to modernize existing production capacities, integrate into global supply chains, and develop export directions with high added value. Creating a comprehensive industrial policy focused on innovation, environmental sustainability, and international partnerships will enable Ukraine to strengthen its position among leading players in the titanium industry.



SECTION 2.

UKRAINE'S TITANIUM INDUSTRY

Ukraine possesses some of the world's largest reserves of titanium ores and has traditionally been a leading player in the global market. The geological diversity of its deposits—from placer to hard-rock—provides a foundation for establishing a complete production cycle, from ore extraction to the production of metallic titanium and its compounds.

Historically, Ukraine's titanium industry developed in an integrated manner: during the Soviet era, the country ensured the extraction of ilmenite and rutile, as well as the production of titanium sponge and titanium dioxide. After gaining independence, Ukraine inherited a robust production infrastructure, but market transformations were accompanied by a lack of investment and delays in modernizing technological facilities.

Currently, the industry operates under the challenges of wartime risks, infrastructure destruction, and blockades of traditional export routes. These factors have significantly impacted production and trade, forcing companies to seek alternative logistical solutions. At the same time, the strategic importance of titanium for the global economy creates opportunities for Ukraine to integrate into international supply chains, particularly in partnerships with the EU and the USA.

This section aims to provide a comprehensive analysis of the state of Ukraine's titanium industry. It examines:

- Historical development (2.1);
- Current mineral resource base (2.2);
- Production capacities and key players (2.3);
- Export potential and its dynamics (2.4).

Special attention is given to the modernization of enterprises, environmental responsibility, and prospects for vertical integration. International financial support (e.g., from the EBRD and World Bank) opens opportunities for implementing innovations, developing environmentally friendly technologies, and digitizing production processes.



2.1. HISTORICAL OVERVIEW OF UKRAINE'S TITANIUM INDUSTRY

The formation of Ukraine's titanium industry began in the 1950s and 1960s with the discovery of the first deposits within the Ukrainian Crystalline Shield. In 1961, the Irshansk Mining and Processing Plant was launched, followed by the Vilnohirsk Mining and Processing Plant, initiating large-scale extraction of ilmenite and rutile ores.

In parallel with the development of the raw material base, metallurgical capacities were established. In 1964, the Zaporizhzhia Titanium-Magnesium Plant (ZTMK) began operations, becoming the main producer of titanium sponge for the entire USSR. In 1969, the Krymskyi Titan plant in Armyansk started producing titanium dioxide using the sulfate process, enabling the formation of a complete technological cycle—from extraction to chemical processing.

Scientific support was provided by the Institute of Titanium of the National Academy of Sciences of Ukraine (previously a sectoral organization for titanium technology development), which, since the 1990s, has actively collaborated with international research centers and supported the development of new melting and processing technologies.

After gaining independence, Ukraine inherited the Soviet Union's main titanium assets—two mining and processing plants, ZTMK, and Krymskyi Titan. This preserved technological potential, but the transition to a market economy in the 1990s led to a decline in production due to disrupted cooperative ties and lack of investment.

The industry's revival began in the 2010s. In 2011, Velta built a modern mining and processing complex at the Birzulivske deposit, becoming a leading private producer of concentrates. Its products were supplied, among others, to the American company Chemours. By 2020, Ukraine's share in global titanium ore production was approximately 7%.

The onset of full-scale war in 2022 led to a sharp decline in production and exports due to infrastructure destruction and logistical constraints. However, Ukraine intensified international cooperation, signing agreements with partners to modernize production and support the export of high-value-added products. According to USGS-2025, Ukraine's share in global titanium ore production in 2024 fell to approximately 1.3% for ilmenite (120,000 tonnes of TiO_2 out of 8.9 million tonnes) and 2.2% for rutile (10,000 tonnes out of 450,000 tonnes).

Current research in Ukraine focuses on electron-beam remelting of alloys, improving metal purity, and developing titanium powder technologies for additive manufacturing. Production processes are gradually integrating digital solutions, including automated ore quality control, predictive equipment maintenance, and environmental risk management systems.

Thus, Ukraine's titanium industry has over half a century of development history, has overcome structural crises, and retained key technological competencies. Its further recovery and development depend on enterprise modernization, investment attraction, and expanded international partnerships.



2.2. CURRENT STATE OF UKRAINE'S TITANIUM MINERAL BASE

Ukraine holds one of the world's largest reserves of titanium ores, estimated at approximately 20% of global resources. According to USGS-2025, proven ilmenite reserves in Ukraine are estimated at about 5.9 million tonnes of TiO_2 , while rutile reserve estimates are not provided. However, actual concentrate production in 2023 accounted for about 7% of global volume, and in 2024, Ukraine's share was approximately 1.3% for ilmenite and 2.2% for rutile (USGS-2025).

The main reserves are concentrated in heavy sand placer deposits containing ilmenite and rutile. The Irshansk and Vilnohirsk deposits, developed by their respective mining and processing plants, are of key importance. According to USGS classification, these deposits fall under categories R1 and C2, indicating a high degree of reserve confirmation.

The utilization of the resource base's potential remains limited: on average, 40–50% of explored reserves are in operation. The reasons include economic and infrastructural constraints, and since 2022, war-related factors. The full-scale aggression led to a production decline of over 50% due to infrastructure destruction, logistical challenges, and loss of access to some sites.

Ukraine's State Program for the Development of the Mineral Resource Base until 2030 envisages expanding geological exploration and searching for new deposits. However, progress is slow due to funding shortages and security risks.

Key Challenges:

- Accumulation of enrichment process waste, requiring modern disposal and water management technologies;
- Equipment wear and insufficient automation of production processes;
- Limited access to financing for developing new sites.

Prospective Development Directions:

- Implementation of digital technologies for deposit monitoring and reserve modeling;
- Use of artificial intelligence to optimize supply chains;
- Modernization of waste storage systems and environmental control.

The industry's sustainability directly depends on stabilizing the security situation, attracting investments, and developing vertically integrated projects that combine extraction, sponge production, and concentrate processing into high-value-added products.



2.3. PRODUCTION CAPACITIES AND KEY PLAYERS

Ukraine's titanium industry is represented by a complex of enterprises covering the entire production cycle—from ore extraction to the production of semi-finished products. Historically, the system consisted of four main components: Irshansk and Vilnohirs'k Mining and Processing Plants (extraction of ilmenite and rutile), Zaporizhzhia Titanium-Magnesium Plant (titanium sponge production), and Krymskyi Titan (titanium dioxide production).

Existing Mining and Processing Enterprises:

- **Irshansk Mining and Processing Plant (Zhytomyr Region):** Specializes in ilmenite extraction. Capacity up to 800,000 tonnes of concentrate per year. The plant modernized its flotation lines in the 2010s but has been operating intermittently since 2022.

- **Vilnohirs'k Mining and Processing Plant (Dnipropetrovsk Region):** Produces ilmenite and rutile, with a capacity of 1 million tonnes of concentrate. Until 2021, it was Europe's largest producer.

- **Velta (Kirovohrad Region):** A private company operating the Birzulivske and Likarivske deposits. Capacity around 200,000 tonnes of concentrate. The company is actively investing in developing its own capacities for producing titanium powders for additive manufacturing.

* Note: The assets of JSC "United Mining and Chemical Company" (UMCC) were acquired by NEQSOL in 2024; in May 2025, the Antimonopoly Committee of Ukraine approved the concentration with conditions; projected viability: Vilnohirs'k—until 2030, Irshansk—at least 15 more years.

Processing and Metallurgy:

- **Zaporizhzhia Titanium-Magnesium Plant (ZTMK):** The only titanium sponge producer in Europe. Designed capacity is 20,000 tonnes per year, but actual output in 2021 was about 5,000 tonnes. Production was halted in 2022 due to hostilities, reagent shortages, and energy constraints. The plant requires modernization, including the replacement of energy-intensive furnaces

and the introduction of induction reactors, but prospects for resuming production have not been officially announced.

- **Krymskyi Titan (Armyansk, temporarily occupied Crimea):** Produces titanium dioxide using the sulfate process, with a capacity of up to 120,000 tonnes per year. The facility has been inaccessible since 2014.

- **Sumykhimprom (Sumy):** The only titanium dioxide producer in Ukraine; after a downtime, it resumed limited operations in 2023–2024.

New Projects and Private Initiatives:

- **Velta:** Implements a program to create a complete titanium production chain—from concentrate to finished powders. Since 2022, the company has been negotiating with the USA and EU regarding the localization of new capacities.

- Several smaller companies are developing deposits in Zhytomyr, Dnipropetrovsk, and Kirovohrad regions, but their contribution to the overall balance remains minor.

Key Challenges of Production Infrastructure:

- Outdated equipment and energy-intensive technologies;
- Risks associated with ongoing hostilities;
- The need to comply with international quality standards (AMS, ASTM) to access aerospace and medical markets.

To transform existing production assets into a competitive value-added chain, it is advisable to consider the creation of a specialized Ukrainian titanium cluster. Such a cluster would unite mining, processing, and metallurgical enterprises, provide shared infrastructure and transparent rules for investors, and create conditions for producing high-value-added products. The cluster concept is detailed in Section 4.4.

Conclusion: Ukraine's titanium industry retains a strong resource base and certain production competencies but requires comprehensive modernization. The restoration and development of ZTMK, attraction of foreign investments, and adoption of new technologies will determine Ukraine's competitiveness in global supply chains.

2.4. EXPORT POTENTIAL AND DYNAMICS

Ukraine has traditionally been among the top five global exporters of titanium concentrates. Until 2021, annual exports of ilmenite ores and concentrates ranged from 500,000 to 600,000 tonnes, accounting for approximately 7% of global trade. The main buyers were the USA, Czech Republic, Poland, Turkey, and China. A significant share was supplied to companies such as Chemours (USA) and Precheza (Czech Republic).

Impact of the Full-Scale War: Since 2022, exports have decreased by more than half due to the destruction of port infrastructure, blockades of maritime routes, and limited railway logistics capabilities. Some contracts were redirected to overland routes through Poland and Romania, but transportation costs increased by 25–40%.

Export Structure in 2023–2024:

- Ilmenite concentrates: over 85% of total volume;
- Rutile: 10%;
- Titanium slag and other primary processed products: approximately 5%.

Exports of titanium sponge from Ukraine have effectively ceased due to the suspension of operations at the Zaporizhzhia Titanium-Magnesium Plant (ZTMK). Titanium dioxide has not been part of the export portfolio since the loss of control over Krymskyi Titan in 2014.

Regional Dynamics:

- The EU remains the primary market, accounting for over 50% of Ukraine's exports.
- The USA holds strategic importance, particularly within agreements to supply critical materials for the aviation and defense industries.
- China and Turkey remain significant consumers of concentrates, though supply volumes are unstable due to logistical risks and political factors.

Prospects:

- The EU, under the Critical Raw Materials Act, views Ukraine as a key partner for diversifying supply sources. This opens prospects for long-term contracts and joint investments in vertically integrated projects.
- The USA, through initiatives to secure critical minerals, is also strengthening cooperation with Ukraine.

Further export development will depend on modernizing production capacities, creating added value within Ukraine, and developing alternative logistics (notably Danube ports and railway corridors).

Detailed quantitative and qualitative indicators, including export capacity per capita and comparisons with leading exporting countries, are provided in Appendix B. These enable an assessment of not only absolute export volumes but also Ukraine's relative competitive position in the global market.

Conclusion:

Despite wartime challenges, Ukraine retains its status as a significant player in the global titanium concentrate market. Strategic integration with the EU and USA, restoration of titanium sponge production, and development of high-tech segments can transform the country from a raw material supplier into a producer of high-value-added products.



CONCLUSION TO SECTION 2

Ukraine possesses a unique mineral resource base, accounting for approximately one-fifth of global titanium ore reserves. The historically developed production complex ensured a full cycle—from concentrate extraction to the production of metallic titanium and titanium dioxide. However, the legacy of Soviet infrastructure, a lack of large-scale investments in the 1990s–2010s, and the destructive impact of war have led to the decline of significant capacities.

Despite this, the country retains key competencies and strategic potential:

- Large deposits of ilmenite and rutile;
- Operational mining and processing plants (Irshansk, Vilnohirsk, Velta);
- A scientific and technological base (Institute of Titanium, sectoral research centers);
- International partnerships strengthening integration into global supply chains.

The main challenges facing the industry are related to the high energy intensity of production, outdated equipment, the loss of Krymskyi Titan, and the suspension of ZTMK operations. The war has exacerbated risks: export volumes have halved, and logistics have become more complex and costly.

At the same time, geopolitical changes create new opportunities. The EU and USA view Ukraine as a strategic partner in supplying critical minerals. International financial support opens pathways to modernization, the adoption of environmentally friendly technologies, and the development of high-value-added products (titanium sponge, powders for additive manufacturing, specialized alloys).

Thus, Ukraine's titanium industry is at a turning point: restoration and modernization of production can transform it from a raw material supplier into one of the key players in the global market with a high share of finished products. This will require a targeted industrial policy, investments in science and technology, and deeper integration with NATO and EU partners.



SECTION 3.

GLOBAL VALUE CHAINS IN THE TITANIUM INDUSTRY

The titanium industry forms a complex, multi-level value chain that encompasses mineral extraction, beneficiation, sponge production, ingot smelting, semi-finished product manufacturing, and final product creation. The value of titanium increases exponentially from raw material to high-tech products, underscoring the critical role of vertical integration and control over all stages.

Global supply chains are concentrated among a small number of countries and companies. Leading players include the USA, Japan, China, and Russia, which control sponge and ingot production, as well as integrated aerospace corporations (Boeing, Airbus, Rolls-Royce). The growing role of China, which combines extraction, processing, and consumption, is reshaping market dynamics and increasing risks of concentration.

For raw material-exporting countries, the ability to move up the value chain—from selling concentrates to producing sponge, ingots, and high-tech products—is crucial. This not only enhances economic benefits but also ensures more stable integration into global markets.

The following subsections examine:

- Key stages of the value chain (3.1);
- Major players and integrated business models (3.2);
- Global risks and vulnerabilities of supply chains (3.3).



3.1. STAGES OF THE VALUE CHAIN

The titanium industry's value chain consists of several key stages, each forming a distinct market segment and determining the level of economic benefits for participants.

1. Extraction and Beneficiation of Ores:

- Main minerals: ilmenite ($\approx 90\%$ of the market) and rutile ($\approx 10\%$).
- Technological processes include gravity and flotation beneficiation methods.
- Product: concentrate with 50–65% TiO_2 content for ilmenite and over 85% for rutile.
- Added value: low, with prices largely determined by global market conditions.

2. Production of Titanium Slag:

- Ilmenite undergoes thermal processing (carbothermic reduction), resulting in slag with increased TiO_2 content (75–85%).
- Slags are used in titanium dioxide or sponge production.
- Added value: medium, with more standardized products.

3. Production of Titanium Sponge:

- Key technology: Kroll process.
- Product: metallic sponge with 98–99.7% titanium content, suitable for remelting.
- Value: 10–12 times higher than concentrate.
- Added value: high, with a limited number of producers creating barriers to entry.

4. Smelting of Ingots and Semi-Finished Products:

- Electron-beam and vacuum-arc furnaces are used.
- Products: titanium ingots, slabs, bars, sheets.
- Value: 20–30% higher than sponge.
- Critical stage for certification to international standards (AMS, ASTM).

5. Production of Alloys and Finished Components:

- Main applications: aerospace and medical alloys (Ti-6Al-4V, Ti-6Al-2Sn-4Zr-2Mo), powders for 3D printing.
- Consumers: aerospace industry, defense sector, medical field.
- Added value: highest; final products can be 50–100 times more expensive than raw materials.

6. Waste Utilization and Recycling:

- Titanium scrap accounts for a significant market share (up to 25% in the USA and EU).
- Secondary processing reduces costs and environmental impact.

Conclusion:

Economic efficiency in the titanium industry directly depends on a country's ability to move “up” the value chain. The lowest revenues come from exporting concentrates, while the greatest benefits are gained by producers of certified alloys and finished components for aerospace and medical applications.



3.2. KEY PLAYERS AND INTEGRATED BUSINESS MODELS

The global titanium market is characterized by high concentration. Only a few countries and corporations control critical production stages—from sponge to certified alloys and finished components for aerospace and defense industries.

Sponge and Ingot Producers:

- **China:** The largest producer of titanium sponge (over 70% of global output). Major companies include BaoTi Group, Shaanxi Tianyu, and Pangang Group, focused on the domestic market and industrial applications; certification for aerospace is limited.

- **Japan:** Companies like Toho Titanium and OSAKA Titanium Technologies supply high-purity sponge and ingots to aerospace corporations such as Boeing and Airbus.

- **Russia:** VSMPO-AVISMA corporation, one of the largest producers of ingots and semi-finished products for aerospace and defense industries.

- **Kazakhstan:** Ust-Kamenogorsk Titanium-Magnesium Plant, supplying sponge to Japanese and European consumers.

- **USA:** TIMET (a subsidiary of PCC, owned by Berkshire Hathaway), controlling key capacities for sponge, ingot, and semi-finished product production.

Integrated Corporations:

- **Boeing, Airbus, Rolls-Royce:** Drive demand for titanium alloys and are directly integrated into supply chains through long-term contracts with sponge and ingot producers.

- **Allegheny Technologies (ATI, USA):** Produces alloys and semi-finished products with a focus on defense and petrochemical sectors.

- **RTI International Metals (USA, acquired by PCC):** Specializes in medical implants and aerospace components.

Business Models:

- **Vertical Integration:** Companies control the entire cycle from sponge to finished components. Examples: VSMPO-AVISMA, TIMET, Toho Titanium. Advantages: stable supply, compliance with standards, higher margins. Disadvantages: significant capital investment.

- **Specialization in Specific Stages:** Common in China, where most producers focus on sponge and semi-finished products without entering the global aerospace alloy market.

- **Partnership Alliances:** Producers sign long-term contracts with aerospace corporations to ensure guaranteed supplies (e.g., Toho Titanium and Airbus).

- **Customer-Contractor Models:** Used in aerospace component production, where outsourcing companies manufacture parts based on designs from major OEMs.

Trends:

- Increasing role of China as the largest sponge producer with limited presence in the aerospace sector.

- Deepening vertical integration in the USA, Japan, and EU to reduce dependence on external suppliers.

- Growth of additive manufacturing technologies, boosting demand for titanium powders and creating a new market segment.

Conclusion:

The global titanium market is characterized by a narrow group of key players capable of producing products for aerospace and defense applications. Access to these segments is possible only with full compliance with international standards and long-term contracts with integrated corporations.

3.3. GLOBAL RISKS AND VULNERABILITIES OF SUPPLY CHAINS

Titanium supply chains are highly concentrated and dependent on a limited number of countries and corporations, creating systemic risks exacerbated by geopolitical and economic factors.

1. Geopolitical Risks:

- Military conflicts and sanctions directly impact supply. For example, restrictions on exports from Russia's VSMPO-AVISMA after 2022 forced aerospace manufacturers to shift to Japan and the USA.
- China's dominance in sponge production (over 70% of global output) creates risks of monopolistic influence on pricing and market access.

2. Economic Risks:

- The high energy intensity of the Kroll process makes production dependent on electricity prices. In countries with unstable tariffs (e.g., Kazakhstan, Saudi Arabia), this affects costs and long-term contracts.
- Cyclical demand in the aerospace sector leads to sharp price fluctuations for sponge and ingots. The COVID-19 pandemic in 2020–2021 caused a 20–25% drop in demand, halting several production lines.

3. Technological Risks:

- Dependence on the Kroll process, in use for over 70 years, makes the industry vulnerable to innovative breakthroughs. If alternative methods (e.g., electrochemical reduction of TiCl_4 , plasma metallurgy) prove economically viable, producers that fail to adapt may lose market share.
- High certification requirements (AMS, ASTM) complicate market entry for new players in the aerospace sector.

4. Environmental and Social Risks:

- The sulfate process for titanium dioxide production generates large volumes of gypsum waste, posing environmental and social acceptance risks.
- Increasing environmental standards in the EU and USA raise entry barriers and require producers to adopt closed-loop and "green" technologies.

5. Logistical Risks:

- A significant portion of titanium concentrate supply relies on maritime routes. Port blockades or disruptions in shipping (e.g., in the Black Sea after 2022) can paralyze exports from entire regions.
- The limited number of certified carriers for sensitive cargo (aerospace-grade alloys) creates bottlenecks in global logistics.

Conclusion:

Global titanium value chains are vulnerable due to production concentration, technological conservatism, and dependence on a few consuming sectors. To minimize risks, participating countries are increasing source diversification, investing in new technologies, and building strategic reserves.

CONCLUSION TO SECTION 3

Global titanium value chains are formed by a narrow group of countries and corporations controlling critical production stages. The highest profits are generated at the level of certified alloys and finished components for aerospace and medical industries, while exporting concentrates yields minimal benefits.

Key players—USA, Japan, China, and Russia—employ various business models, from full vertical integration to narrow specialization. Meanwhile, aerospace corporations (Boeing, Airbus, Rolls-Royce) act as strategic customers, effectively setting market standards and structure.

High production concentration creates systemic risks:

- Geopolitical (sanctions, military conflicts, China's monopolization of supply);
- Economic (aerospace demand cyclicity, energy dependence);
- Technological (Kroll process dominance, innovation barriers);
- Environmental (strict waste disposal standards and transition to green technologies);
- Logistical (reliance on maritime routes and limited certified carriers).

Strategic market development directions are driven by three factors:

1. **Supply diversification**—seeking new raw material sources in Africa and South America.
2. **Technological innovation**—developing alternative sponge production methods and advancing additive manufacturing.
3. **Environmental transformation**—adopting closed-loop cycles and reducing emissions.

For Ukraine, this analysis underscores the need to move up the value chain—from exporting concentrates to producing sponge, alloys, and powders. Integration with European and American partners, restoration and modernization of ZTMK, and support for innovation can elevate Ukraine to a new level of participation in global supply chains.

SECTION 4.

PROSPECTS FOR THE DEVELOPMENT OF UKRAINE'S TITANIUM INDUSTRY

The future of Ukraine's titanium industry is shaped by a combination of three factors: the availability of a unique mineral resource base, geopolitical challenges, and global trends in titanium demand. Ukraine is among the few countries capable of supporting a full production cycle—from ore extraction to the production of metal and its compounds. This creates the foundation for building competitive advantages, but realizing this potential depends on large-scale modernization and attracting investments.

The current state of the industry is characterized by a decline in production due to the war, the loss of some production capacities, and challenges with export logistics. External demand, driven by the aerospace, defense, and medical industries, is growing, opening a unique window of opportunity for Ukraine, as the EU and the US seek reliable suppliers of critical raw materials and finished products to reduce dependence on China and Russia.

Further development of the industry should focus on three key priorities:

1. Modernization of production infrastructure—restoration and technical re-equipment of the Zaporizhzhia Titanium-Magnesium Plant, automation of mining and beneficiation enterprises.

2. Integration into global value chains—shifting from exporting concentrates to producing sponge, ingots, powders, and certified alloys.

3. Environmental and technological transformation—adopting “green” technologies, digitizing production, and developing innovative areas, such as additive manufacturing.



4.1. NEW TITANIUM PRODUCTION TECHNOLOGIES

Ukraine's titanium industry has significant resource potential, but its production facilities remain outdated and energy-intensive. Comprehensive investments are needed to modernize equipment, implement energy-saving technologies, and improve environmental standards.

Key investment directions:

1. Ore extraction and beneficiation

- Modernization of crushing and beneficiation plants;
- Implementation of automated systems for ore quality control;
- Development of new quarries based on promising deposits (Zhytomyr and Kirovohrad regions).

2. Titanium sponge production

- Reconstruction of the Zaporizhzhia Titanium-Magnesium Plant;
- Replacement of Kroll process furnaces with induction reactors to reduce energy consumption by 15–20%;
- Development of alternative technologies (e.g., electrolytic reduction of TiCl_4).

3. Processing and production of semi-finished products

- Installation of modern electron-beam and vacuum-arc furnaces;
- Expansion of capacities for producing ingots and rolled sheets;
- Establishment of powder metallurgy lines for additive technologies (e.g., Velta LLC, which has received its third US patent for a waste-free chloride process for powder production and is launching a pilot line with a capacity of 0.4 tons/month).

4. Infrastructure and logistics

- Development of railway corridors and Danube ports for exports;
- Creation of warehouses and logistics hubs near enterprises;
- Digitization of supply chain tracking processes.

Estimated investment needs (by 2030):

- Extraction and beneficiation: \$0.8–1 billion USD;
- Sponge production: \$1.5–2 billion USD;
- Semi-finished products and powders: \$1.2–1.5 billion USD;
- Logistics and infrastructure: \$0.5 billion USD.

Funding sources:

- International financial institutions (World Bank, EBRD, EIB);
- Partnership programs with the EU and US under the Critical Raw Materials Act and the Agreement between the Government of Ukraine and the Government of the US on establishing the American-Ukrainian Reconstruction Investment Fund;
- Private investments, including through public-private partnerships;
- Preferential lending programs for the titanium industry.

The effectiveness of modernization investments should be evaluated using a system of labor productivity, resource, and energy efficiency indicators, detailed in Annex B. This will link investment decisions to tangible industry transformation outcomes.

Conclusion.

Modernizing Ukraine's titanium industry is impossible without systemic investments. The key task is the restoration and modernization of the Zaporizhzhia Titanium-Magnesium Plant as the central hub for sponge production and creating conditions for producing high-value-added products. This will enable Ukraine to transition from a raw material supplier to an integrated participant in the global market.

4.2. ENVIRONMENTAL AND TECHNOLOGICAL TRANSFORMATION

The sustainability of Ukraine's titanium industry depends not only on production modernization but also on its ability to adapt to new environmental standards and technological trends. Stricter regulatory requirements in the EU and US make the transition to “clean” technologies a prerequisite for accessing key markets.

Environmental priorities:

- Transition to closed-loop cycles in titanium sponge production (reusing Mg and Cl);
- Implementation of wastewater treatment systems and reduction of acidic waste at mining and beneficiation plants;
- Land reclamation after mining operations;
- Monitoring emissions and integrating ESG principles into corporate governance.

Technological transformations:

1. Energy efficiency. Using induction reactors and optimizing thermal processes can reduce energy consumption by 15–20%.
2. Alternative production methods. Research into electrolytic reduction of TiCl_4 and plasma metallurgy offers prospects for replacing the Kroll process.
3. Powder metallurgy and additive manufacturing. Developing lines for titanium powder production will enable integration into new global market segments.
4. Production digitization. Using big data, artificial intelligence, and IoT for equipment monitoring, failure prediction, and logistics optimization.
5. Recycling. Increasing the share of titanium waste in the production cycle (up to 20–25% of total volume) reduces dependence on primary raw materials and energy costs.

Recycling.

It is worth noting that waste from the mining industry accounts for the largest share of all waste in Ukraine. This waste is generated during the extraction, beneficiation, and processing of minerals. As of 2019, Ukraine had 465 tailings storage facilities. Out of the 6,042 million tons of recorded waste at that time, 5,404 million tons were from the mining and metallurgical (processing) industries, corresponding to 320 tailings facilities. Additionally, 75% of these facilities are located in southern Ukraine, increasing the risk of technogenic accidents due to ongoing hostilities. Over half of the generated waste, after preliminary sorting or fractionation, could be reprocessed as mineral raw materials or sold to other economic sectors for reuse (e.g., crushed stone from ore mining or ash for cement production from coal mining).

Conclusion.

Environmental and technological modernization is not optional but a necessity. Ukraine's ability to implement energy-efficient and “clean” solutions will determine its integration into European and American markets and strengthen its position in global competition.

4.3. INTERNATIONAL COOPERATION AND GLOBAL MARKET INTEGRATION

The future of Ukraine's titanium industry largely depends on its integration into global supply chains and the development of strategic partnerships. Amid geopolitical instability and war-related risks, international cooperation ensures access to financing, technologies, and stable markets.

Key cooperation directions:

1. European Union

- Ukraine is included in the priority list of partners under the Critical Raw Materials Act.
- The EU views Ukraine as a source of critical minerals to reduce dependence on China and Russia.
- Opportunities: long-term supply contracts, joint investments in sponge and powder production, access to EIB and EBRD financial instruments.

2. United States

- Partnership in critical materials involves integrating Ukrainian resources into supply chains for the aerospace and defense industries.
- Promising areas: joint R&D in additive technologies, certification of Ukrainian sponge and alloys to American AMS standards.

3. International financial institutions

- The World Bank, EBRD, IFC, and other institutions already support energy and infrastructure projects, creating a foundation for titanium industry investments.
- Emphasis is placed on “green” technologies and ESG standards.

4. Private corporations

- Cooperation with global manufacturers (Boeing, Airbus, Rolls-Royce, Chemours) is possible through long-term supply agreements and localized production in Ukraine.
- Promising projects include powder metallurgy for 3D printing and medical components.

Integration challenges:

- Need for compliance with international quality and certification standards;
- High risks for investors due to the war;
- Limited modern production capacities.

Conclusion.

International cooperation is a critical factor in developing Ukraine's titanium industry. Strategic alliances with the EU and US, securing financing from international institutions, and partnerships with global corporations will enable Ukraine to shift from a raw material model to producing high-value-added products and secure a place among leading global titanium market participants.



4.4. UKRAINIAN TITANIUM RAW MATERIALS CLUSTER

A critical minerals cluster is a territorially concentrated group of enterprises covering the entire production chain: from ore extraction and concentrate beneficiation to the production of sponge, ingots, powders, and finished components. It operates under a special legal regime, has shared infrastructure, and ensures transparent rules for investors.

For Ukraine, creating a titanium raw materials cluster is a key tool for transitioning from raw material exports to high-value-added production. The cluster will reduce investment risks through special access rules, international arbitration, and centralized infrastructure while ensuring compliance with EU and US certification and environmental standards.

Expected benefits of the cluster:

- Attraction of long-term investments and advanced technologies;
- Diversification of exports from concentrates to certified alloys, powders, and products for aerospace, defense, and medical industries;
- Development of local supply chains, increased employment, and tax revenues;
- Implementation of unified environmental responsibility and energy efficiency standards.

Key elements of the cluster design:

- Development of infrastructure (railway, port, and road logistics, energy, water supply);
- Tax and customs incentives for deep processing;
- Ensuring access to raw materials for residents based on market formulas;
- Simplification of licensing and permitting procedures;
- Application of international arbitration to protect investors;
- Creation of a certification and research center for powder metallurgy and additive technologies.

International experience confirms the effectiveness of this model: Indonesia is developing nickel clusters with public-private co-financing, China is advancing a rare earth metals cluster in Baotou, and the EU, under the Critical Raw Materials Act, designates strategic projects functioning as processing hubs. For Ukraine, establishing a titanium cluster could be a practical step toward securing its position in global critical minerals supply chains.



CONCLUSION TO SECTION 4

The prospects for Ukraine's titanium industry are determined by a combination of its resource potential and global market trends. Despite significant challenges caused by the war, the suspension of certain enterprises, and logistical constraints, Ukraine retains the opportunity to transform its role in the global titanium industry.

Key development directions:

- **Production modernization.** Restoring the Zaporizhzhia Titanium-Magnesium Plant and upgrading mining and beneficiation enterprises will ensure stable sponge and concentrate production.

- **Technological and environmental transformation.** Adopting energy-efficient and “green” technologies, developing powder metallurgy, and additive manufacturing will facilitate entry into new market segments.

- **International integration.** Partnerships with the EU and US, support from international financial institutions, and collaboration with global corporations provide the foundation for transitioning from a raw material model to high-value-added production.

Ukraine's strategic task is to move “up” the value chain—from exporting concentrates to producing certified alloys, powders, and finished products. Achieving this requires large-scale investments, a stable regulatory environment, and security guarantees for international partners.

Thus, the titanium industry can become a driver of Ukraine's economic recovery and integration into the global economy. Successful modernization and international cooperation can transform the country from a raw material supplier into a strategic producer of critical materials for high-tech sectors.



SECTION 5. CONCLUSIONS AND RECOMMENDATIONS

Titanium is a critical strategic material in the modern economy, with its market shaped by high technological demands and geopolitical factors. The analysis conducted highlights key trends, challenges, and opportunities at both global and Ukrainian levels.

The global titanium market is expanding, driven by growth in the aerospace, defense, medical, and chemical industries. The production of concentrates, sponge, and titanium dioxide is highly concentrated in a small number of countries, posing risks to global supply chains. The industry's gradual environmental and technological transformation creates opportunities for innovative players offering energy-efficient and environmentally sustainable solutions.

For Ukraine, the titanium industry is strategically vital as a driver of economic growth, integration into global markets, and strengthening its position in the critical minerals sector. However, its development is hindered by outdated technologies, war-related risks, and reliance on exporting low-value-added raw materials.

This section summarizes the study's key findings and provides recommendations for government policy, international partners, and businesses.



5.1. KEY FINDINGS

1. The global titanium market is growing. Demand is primarily driven by the aerospace industry (over 50%), industrial applications (≈ 25%), and the defense sector. Further consumption growth is anticipated due to advancements in air transportation, medical technologies, and additive manufacturing.

2. Titanium sponge production is highly concentrated. China controls over 70% of global output, while Japan, Russia, and the US dominate the production of high-quality products for aerospace. This concentration creates risks of monopolization and dependence on a limited pool of suppliers.

3. The technological base is slow to evolve. New technologies are adopted gradually, giving an edge to early innovators. Most production relies on the energy-intensive and environmentally challenging Kroll process. Innovative alternatives, such as electrolytic and plasma methods, remain in research and pilot stages.

4. Environmental standards shape competitiveness. Transitioning to “green” technologies and closed-loop production is a prerequisite for accessing EU and US markets, creating barriers to entry and further industry development.

5. Ukraine has significant resource potential. Its titanium ore reserves account for approximately 20% of global reserves. Key assets include the Irshansk and Vilnohirsk Mining and Processing Plants and the private company Velta LLC, providing a foundation for integrated production.

6. Ukraine faces substantial challenges. The suspension of the Zaporizhzhia Titanium-Magnesium Plant and the loss of Krymskyi Titan have disrupted the production cycle. Concentrate exports have fallen by more than half, with logistics complicated by the war.

7. Opportunities for Ukraine persist. The EU and US view Ukraine as a strategic partner for critical minerals supply. International financial support and innovation partnerships offer prospects for establishing vertically integrated production.

8. Strategic development is achievable. To boost economic benefits and global competitiveness, Ukraine must shift from a raw material model to producing high-value-added products, such as sponge, alloys, and powders for additive manufacturing.

Progress toward these opportunities should be tracked using a system of quantitative and qualitative indicators (Annex B), covering production, economic, social, innovation, and environmental metrics.



5.2. RECOMMENDATIONS FOR THE GOVERNMENT OF UKRAINE

1. Restoration and Modernization of Production

- Initiate a reconstruction program for the Zaporizhzhia Titanium-Magnesium Plant, emphasizing energy efficiency and replacement of obsolete equipment.
- Create incentives for private investment in developing mining and processing enterprises (Irshansk, Vilnohirsk, Velta LLC) with automation and modern environmental control systems.

2. Development of the Value Chain

- Shift from exporting concentrates to producing sponge, ingots, and certified alloys.
- Invest in establishing powder metallurgy lines for additive manufacturing.
- Develop production of medical and aerospace components compliant with AMS and ASTM standards.

3. Integration into Global Markets

- Leverage the EU's Critical Raw Materials Act to secure long-term supply contracts, including participation in announced strategic projects.
- Deepen cooperation with the US on certifying titanium sponge and alloys for aerospace and defense sectors.
- Build strategic alliances with companies like Boeing, Airbus, and Rolls-Royce.

4. Creation of a Ukrainian Titanium Raw Materials Cluster

- Adopt a special law for the cluster, offering a preferential investment regime, simplified permitting procedures, and access to international arbitration.
- Develop shared infrastructure (energy, water supply, railway, and port logistics).
- Ensure transparent access to raw materials for cluster residents based on market formulas and quotas.
- Establish a certification and research center for powder metallurgy and additive technologies (AMS/ASTM).
- Introduce public-private partnerships for "anchor" projects and enforce production localization requirements.
- Align the cluster with the EU's Critical Raw Materials Act (Strategic Project status) and US critical minerals initiatives.

5. Financing and Institutional Support

- Attract funding from international financial institutions (World Bank, EBRD, EIB) for production modernization.
- Implement public-private partnerships for developing new deposits and logistics infrastructure.
- Develop a state program to support innovation in the titanium industry, creating conditions for technology parks, R&D centers, and raw materials clusters. Support mechanisms may include fiscal incentives, elimination of import duties and VAT, replacing profit tax with a tax on withdrawn capital, credit incentives, state guarantees, export support, and promotion of the titanium cluster.

6. Environmental Transformation

- Integrate ESG principles into the corporate governance of titanium enterprises.
- Transition to closed-loop production to minimize waste and emissions.
- Develop standards for environmental land reclamation post-mining.

7. Innovation and Digitization

- Foster collaboration with international research centers on electrolytic and plasma titanium production methods.
- Implement digital systems for production process management, equipment monitoring, and predictive maintenance.
- Promote the creation of Ukrainian R&D hubs for powder metallurgy and additive technologies.

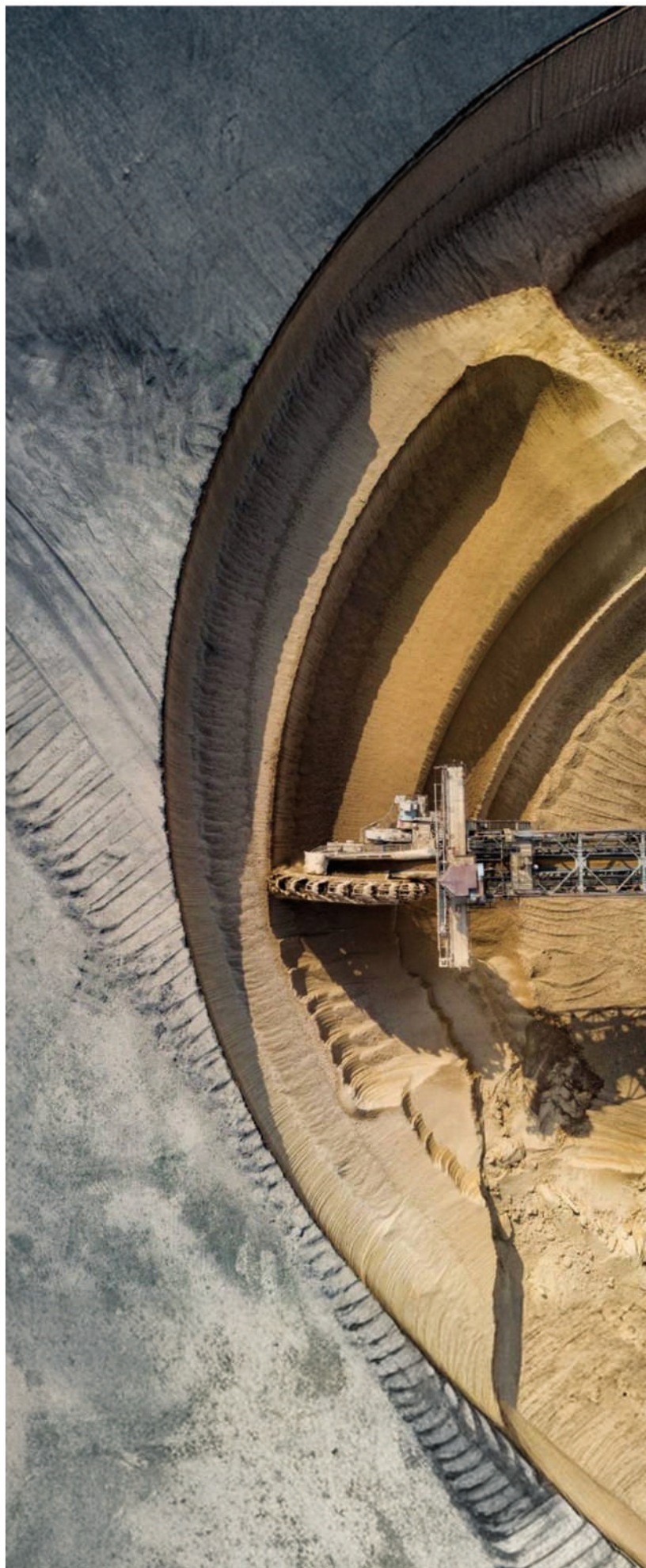
8. Legislative and Regulatory Reforms

- Subsoil Code: Simplify special permit issuance, adopt modern geospatial systems, and increase information disclosure requirements.
- Environmental Impact Assessment (EIA) Legislation: Align with EU practices, adding specific procedures for critical minerals projects.
- Harmonization with EU Legislation: Integrate Critical Raw Materials Act provisions and ESG reporting directives into Ukrainian regulations.
- Public-Private Partnerships: Enhance legislation for the mining industry, particularly for concessions and long-term investment agreements.
- Regulator Reform (State Service of Geology and Subsoil): Digitize processes, implement transparent reserve accounting, and introduce online license compliance monitoring.
- Innovative Directions: Establish a legal framework for powder metallurgy and additive technologies, including product certification under AMS and ASTM standards.

Implementing these recommendations will strengthen Ukraine's position in the global titanium industry, reduce reliance on raw material exports, and integrate it into high-tech global market segments.

State policy in the titanium sector should be accompanied by systematic monitoring of performance indicators (Annex B) to track progress in creating added value, increasing employment, fostering innovation, and adopting energy-efficient and environmentally safe technologies.

Specific legislative change proposals are provided in Annex C.



5.3. RECOMMENDATIONS FOR INTERNATIONAL PARTNERS

1. Support for Ukraine's Integration into Global Supply Chains

- Include Ukrainian enterprises in international critical minerals supply programs.
- Establish long-term contracts for purchasing titanium products from Ukrainian sources.
- Ensure priority access for Ukraine to the EU's Critical Raw Materials Act programs and US critical materials initiatives.

2. Financial and Technical Assistance

- Engage international financial institutions (EBRD, EIB, World Bank) to fund modernization of the Zaporizhzhia Titanium-Magnesium Plant and infrastructure development.
- Provide technical assistance for certifying Ukrainian enterprises under AMS and ASTM standards.
- Support environmental projects, including land reclamation and the transition to “green” technologies.

3. Joint Investment Projects

- Form joint ventures with Ukrainian companies for producing sponge, alloys, and powders.
- Localize production of components for aerospace, medical, and defense industries in Ukraine.
- Develop technology hubs for additive manufacturing and powder metallurgy in collaboration with Ukrainian research centers.

4. Political and Security Support

- Provide risk insurance for foreign investors in Ukraine through international mechanisms (e.g., MIGA).
- Support diplomatic and trade agreements to ensure stable Ukrainian titanium supplies.
- Facilitate Ukraine's integration into European and transatlantic institutional mechanisms for critical minerals.

5. Scientific and Technical Cooperation

- Deepen partnerships in research and development of new titanium production technologies.
- Support technology transfers and joint training programs for Ukrainian engineers and scientists.
- Facilitate Ukraine's participation in Horizon Europe and other international scientific initiatives.

For international partners, investments in Ukraine's titanium industry represent both an economic opportunity and a strategic contribution to diversifying global critical materials supplies. Collaborative efforts will enhance Ukraine's economic resilience and ensure the stability of global supply chains.



5.4. RECOMMENDATIONS FOR BUSINESSES

1. Activity Diversification

- Invest in producing sponge, alloys, and powders for additive technologies, beyond just extracting and beneficiating titanium-containing ores.
- Explore partnerships with international companies to access new markets and certification standards.

2. Innovation and Technological Development

- Adopt digital solutions for production monitoring and supply chain management.
- Develop R&D in electrolytic and plasma titanium production methods.
- Invest in powder metallurgy lines targeting aerospace, medical, and defense industries.

3. Alignment with International Standards

- Certify products under AMS and ASTM standards to access aerospace and medical markets.
- Implement ISO 9001 quality management and ISO 14001 environmental management systems.

4. Environmental Responsibility

- Minimize environmental impact through closed-loop production and efficient waste utilization.
- Integrate ESG principles into corporate strategies to enhance investment attractiveness.

5. Risk Management

- o Use insurance and financial tools to mitigate risks related to war and logistical constraints.
- o Build strategic raw material reserves and consider territorial diversification of production.

6. Collaboration with Research Institutions

- Expand cooperation with Ukrainian and international research centers.
- Fund applied research in metallurgy, additive technologies, and environmentally friendly production.

The key challenge for businesses is transitioning from a traditional raw material model to an innovative, integrated approach. Companies investing in technology, standards, and sustainability will gain a competitive advantage in the global market and contribute to Ukraine's role as a strategic titanium supplier.



FINAL CONCLUSION

The titanium industry is a strategic sector of the global economy, combining high-tech demand, geopolitical importance, and the need for environmentally sustainable development. Global trends indicate growing titanium demand, a highly concentrated market, and significant profits generated from certified alloys and finished components for aerospace, defense, and medical industries.

Ukraine holds unique titanium ore reserves but currently operates primarily as a raw material supplier. The war has significantly limited production and export capabilities, yet it has also opened a window of opportunity for strategic integration with the EU and US, which are actively diversifying critical minerals supply sources.

Ukraine's primary task is to shift from exporting concentrates to producing high-value-added products: titanium sponge, certified alloys, and powders for additive manufacturing.

This requires:

- Large-scale investments in modernizing production facilities;
- Adoption of “green” technologies and digital solutions;
- Development of partnerships with international corporations and research centers;
- Creation of conditions for integration into global supply chains.

For international partners, supporting the restoration and development of Ukraine's titanium industry is both a high-potential investment and a contribution to stabilizing global strategic materials supply chains. For businesses, it is an opportunity to establish a foothold in a growing market with high entry barriers.

Thus, Ukraine's titanium industry can become a key driver of the country's economic recovery, facilitate integration into the European and transatlantic space, and solidify its position as a strategic supplier of critical materials for the 21st century.



APPENDIX A.

SOURCES USED

The following list includes authoritative sources used in the preparation of this study. It encompasses official statistical databases, regulatory acts of the European Union, international reports from recognized organizations (USGS, IMF, World Bank, IEA, OECD, UN institutions), as well as leading industry standards and materials from reputable media. Collectively, these sources provide an empirical and regulatory foundation for the analysis of the global and Ukrainian titanium industry.

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APPENDIX B.

PERFORMANCE INDICATORS FOR UKRAINE'S TITANIUM INDUSTRY

Objective:

To provide a systematic assessment of the state and dynamics of Ukraine's titanium industry, its contribution to the national economy, and its integration into global supply chains. The indicators cover production, economic, social, innovation, and environmental aspects.

1. Production Indicators

1.1. Production Volume

Methodology: Total output of ore, concentrates, sponge, ingots, and powders (thousand tons/year).

Interpretation: A baseline measure of the industry's scale.

1.2. Compound Annual Growth Rate (CAGR) of Production

Formula: $(V_k / V_0)^{(1/n)} - 1$, where V_k is the output in the final year, V_0 is the output in the initial year, and n is the number of years.

Interpretation: Reflects the medium-term growth dynamics of the industry.

2. Economic Indicators

2.1. Industry's Value Added (% of GDP)

Formula: $(\text{Industry value added} / \text{GDP}) * 100$.
Interpretation: Indicates the structural significance of the industry in the national economy.

2.2. Value Added per Capita

Formula: $\text{Industry value added} / \text{Population}$.
Interpretation: Measures the level of industrialization per capita, used for international comparisons.

2.3. CAGR of Value Added

Formula: $(V_k / V_0)^{(1/n)} - 1$, where V_k and V_0 are the value added in the final and initial years, respectively.

Interpretation: Assesses the sustainability of economic growth in the industry.

2.4. Global Market Participation

Formula: $\text{Ukraine's industry value added} / \text{Average value added of the top 10 exporters (or importers)}$.
Sources: UN Comtrade, ITC, USGS.

Interpretation: Determines international competitiveness.

2.5. Export Capability

Formula: $\text{Export revenue} / \text{Population}$.

Interpretation: Measures the ability to generate foreign currency earnings per capita.

3. Social Indicators

3.1. Industry Employment

Methodology: Number of jobs in extraction, processing, and production.

Interpretation: Reflects the industry's social role.

3.2. Employment Structural Weight

Formula: $(\text{Employment in the titanium industry} / \text{Total employment}) * 100$.

Interpretation: Indicates the industry's role in the labor market structure.

3.3. CAGR of Employment

Formula: $(N_k / N_0)^{(1/n)} - 1$, where N_k is the number of employees in the final year, and N_0 is the number in the initial year.

Interpretation: Shows the dynamics of job creation.

3.4. Employment Elasticity

Formula: $\text{CAGR of employment} / \text{CAGR of value added}$.

Interpretation: $0-0.5$ = growth driven by productivity; $0.5-1$ = balanced growth; >1 = growth driven by labor intensity.

3.5. Labor Productivity

Formula: $\text{Value added} / \text{Number of employees}$.

Interpretation: Measures workforce efficiency.

3.6. Wage Level

Formula: $\text{Labor costs} / \text{Number of employees}$.

Interpretation: Represents the average salary in the industry.

4. Innovation and Structural Indicators

4.1. Production Diversification Index (HHI, Herfindahl-Hirschman Index)

Formula: $\sum (s_i^2)$, where s_i is the share of each subsector.

Interpretation: <1500 = low concentration;
1500–2500 = moderate concentration;
>2500 = high concentration.

4.2. Innovation Index

Formula: (Volume of innovative products / Total production volume) * 100.

Interpretation: Share of products from new technologies (e.g., 3D printing, powders, implants).

4.3. Financial Sustainability

Formula: EBITDA / Revenue or R&D expenditure / Revenue.

Interpretation: Measures the ability to invest in development and innovation.

5. Environmental and Resource Indicators

5.1. Resource Efficiency

Formula: Value added / Material intensity.

Material Intensity: (Raw materials used – Raw materials exported).

Interpretation: Efficiency of converting raw materials into value.

5.2. Energy Efficiency

Formula: Value added / Energy consumption (in toe – tons of oil equivalent or tce – tons of coal equivalent).

Interpretation: Dependence of production on energy resources.

5.3. Emissions and Waste

Formula: (CO₂ + Other waste) / Volume of finished products.

Interpretation: Key ESG indicator and compliance with EU/US requirements.

6. Use of Indicators

For the government: Monitoring the implementation of industry development strategies and assessing contributions to GDP, employment, and exports.

For businesses: Analyzing competitiveness, innovation, and production efficiency.

For investors: Evaluating financial sustainability and environmental compliance of enterprises.

For international partners: Comparing Ukraine with leading countries and justifying cooperation.

APPENDIX C. PRACTICAL RECOMMENDATIONS FOR THE GOVERNMENT OF UKRAINE

1. Create conditions for the state and banking sectors to simplify access to affordable debt capital for titanium industry enterprises:

- Develop amendments to the Cabinet of Ministers of Ukraine Resolution № 28 of January 24, 2020, “On Providing Financial State Support” to expand priority lending areas to include mineral extraction.

2. Provide state support for investment projects aimed at modernizing existing and creating new titanium industry production facilities to meet the needs of the defense-industrial complex, aerospace, rocketry, shipbuilding, and medical industries for high-quality titanium products:

- Develop amendments to the Law of Ukraine “On State Support for Investment Projects with Significant Investments” to extend state support to investment projects in mineral extraction.

3. Create conditions for developing extensive transportation systems for supplying titanium raw materials, intermediate, and finished products, including to international markets, with a high level of safety:

- Introduce preferential tariffs for transporting commercial products by rail and port fees for vessels operating under the Ukrainian flag or foreign flags to enhance the competitiveness of Ukrainian products.

4. Revise the system of customs duties on import operations to diversify sources of equipment used in titanium production:

- Develop amendments to the Tax and Customs Codes to exempt relevant goods from import duties and VAT.

5. Introduce fiscal incentives, such as tax holidays Keppel Bay holidays and loans, for investments in existing and new production facilities, particularly in cases of technology transfer to domestic enterprises:

- Replace the corporate profit tax with a tax on withdrawn capital.

6. Ensure an adequate level of cooperation proposals for strategic investors:

- Conduct auctions and tenders for concluding product-sharing agreements for the development of titanium-containing deposits in 2025.

7. Provide state support for connecting new industrial facilities to electrical grids, including the development of electricity supply networks to areas with concentrated titanium industry enterprises, and ensure uninterrupted electricity supply to titanium industry facilities:

- Extend the provisions of the Law of Ukraine “On Industrial Parks” to enterprises participating in the titanium industry cluster.
- Ensure timely and high-quality provision of administrative and informational services to potential investors in the titanium industry, including comprehensive and accurate geological data on titanium ore deposits, based on the “single window” principle.

8. Implement a “single window” system in line with the provisions of Regulation (EU) 2024/1252, “On Establishing a Framework to Ensure a Secure and Sustainable Supply of Critical Raw Materials.”

9. Introduce effective export support mechanisms, including export credit and risk insurance:

- Develop amendments to the Law of Ukraine “On Financial Mechanisms for Stimulating Export Activities” to remove codes 2601–2620 from the Ukrainian Classification of Goods for Foreign Economic Activity to enable credit and insurance support for the export of minerals, including critical raw materials.
- Develop amendments to the Law of Ukraine “On Financial Mechanisms for Stimulating Export Activities” to provide insurance and reinsurance against war-related risks for loans to Ukrainian businesses needed for the development of the mining industry.

10. Create conditions to enhance the competitiveness of Ukrainian products on the global market:

- Amend the Subsoil Code of Ukraine to introduce the concept of “Raw Materials Clusters,” their formation procedures, and the maintenance of a corresponding register.
- Temporarily, until domestic power generation is developed, impose special obligations on universal service providers to supply electricity at preferential rates to participants in the “Raw Materials Cluster.”

