

INFORMAZIONI DIFESA

FUTURE WARS FOR THE DOMINATION OF RARE EARTHS AND RAW MATERIALS:

A Strategic Analysis



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Future Wars for the Domination of Rare Earths and Raw Materials: A Strategic Analysis



Rare earths are a cornerstone of modern military capabilities. Their control not only supports the development of high-tech consumer products, but also provides a significant military advantage, making them critical to national defense strategies.

The 21st century is witnessing a dramatic increase in demand for rare earth elements (REE) and essential raw materials, driven by rapid technological advances, the shift to renewable energy and growing military needs. Rare earths and specific commodities such as cobalt, lithium and nickel have become critical to the global economy, as they are essential for the production of high-tech equipment, electric vehicles, renewable energy systems and military hardware. This dependence has increased the strategic importance of these resources, making control of their supply chains a national security imperative for many countries. While attention to rare earths and commodities often focuses on their role in civil industries, their importance to military applications cannot be underestimated. REEs are essential for the production of advanced weapons, radar systems, missile guidance systems and stealth technologies, giving nations with secure access to these materials a significant advantage in modern warfare. As demand grows and supply remains concentrated in a few regions, future conflicts over these resources appear increasingly likely. This analysis explores the geopolitical landscape of REEs and critical commodities, looking at current and future players, military applications of these materials and potential conflict scenarios. It also examines strategies that could mitigate the risks of wars for control of these vital resources.



REEs are made up of 17 chemically similar elements, including lanthanides such as neodymium, dysprosium and praseodymium, as well as scandium and yttrium. Despite their relative abundance in the Earth's crust, these elements are rarely found in concentrated and economically viable deposits, making their extraction complex and expensive. As a result, the production and refining of REEs is concentrated in a few key regions, notably China, which controls most of the world's supply. REEs have many civil applications, including

- Renewable energy, as they are essential in the production of wind turbines, electric vehicle motors and energy storage systems. As the global shift to renewable energy accelerates, demand for these materials will increase.
- Consumer electronics, where they are essential for modern electronics, including smartphones, laptops and televisions, which rely on their magnetic, conductive and luminescent properties.

On the other hand, REEs are widely used to support advanced military technologies, particularly in the production of high-performance defence systems. Some of the most important military applications include:

- Missile guidance systems: Neodymium and dysprosium are used in the powerful magnets found in missile guidance systems, which require precision and reliability in combat scenarios.
- Stealth technology: radar-absorbing materials used in stealth aircraft and ships often contain rare earth elements to avoid enemy detection.
- Night vision goggles: Yttrium is used in night vision goggles, which are essential for modern military operations.
- Radar and sonar systems: Advanced radar and sonar systems, essential for early warning defence systems and naval operations, have powerful magnets and sensors that use REEs.
- Jet engines: Their high temperature tolerance makes them essential in the production of jet engines used in combat aircraft and other military platforms.

REEs are therefore a cornerstone of modern military capabilities. Their control not only supports the development of high-tech consumer products, but also provides a significant military advantage, making them critical to national defence strategies.

In addition, other raw materials such as cobalt, lithium and nickel have become essential resources



for modern technologies. These materials are critical for the production of lithium-ion batteries used in electric vehicles, renewable energy storage systems and portable electronic devices. The strategic importance of these materials has increased in recent years, particularly due to military applications such as

- military drones for reconnaissance, surveillance and targeted attacks;
- portable military equipment, from communications to navigation systems;
- military electric vehicles, which reduce the carbon footprint of armed forces and improve battlefield logistics, but require large quantities of lithium, cobalt and nickel for their batteries;
- energy storage for military bases in remote or hostile environments, which is safe and reliable but dependent on lithium and cobalt.
- Their military applications highlight their growing importance in both conventional and asymmetric warfare, making control of their supply chains a strategic priority for many nations.

THE CURRENT GLOBAL LANDSCAPE: ACTORS IN THE BATTLE FOR REES AND CRITICAL MATERIALS

China's Strategic Approac

China's success in the REEs sector is the result of long-term strategic initiatives. Through investment and government subsidies, China has systematically developed mining and refining capacity, securing its position as a major producer and refiner. The country has also expanded its global presence through investments in Africa, Latin America and Central Asia, securing access to key commodities beyond its borders. China's Belt and Road Initiative (BRI) has further cemented its dominance by connecting resource-rich countries to Chinese infrastructure and creating dependencies on its supply chains.

China is the undisputed leader in REEs production and refining, controlling around 60% of global production and over 80% of refining capacity.

China's approach to REEs and critical commodities is deeply rooted in its long-term economic and geopolitical strategy. As the world's largest producer and refiner, it has developed a dominant position that gives it considerable influence in global markets, particularly in the technology and defence sectors. It is the result of state initiatives that have systematically increased China's capacity to extract, process and export these vital materials.

At the heart of China's strategy is state investment. The Chinese government has long recognised the strategic importance of REEs, not only for civil industries but also for military applications. As a result, Beijing has invested considerable resources in developing domestic mining and refining industries. Generous subsidies and a favourable regulatory environment have enabled Chinese companies to overcome global competition and secure control of most of the world's REEs production and processing, even beyond its borders, through strategic acquisitions and investments in other countries.

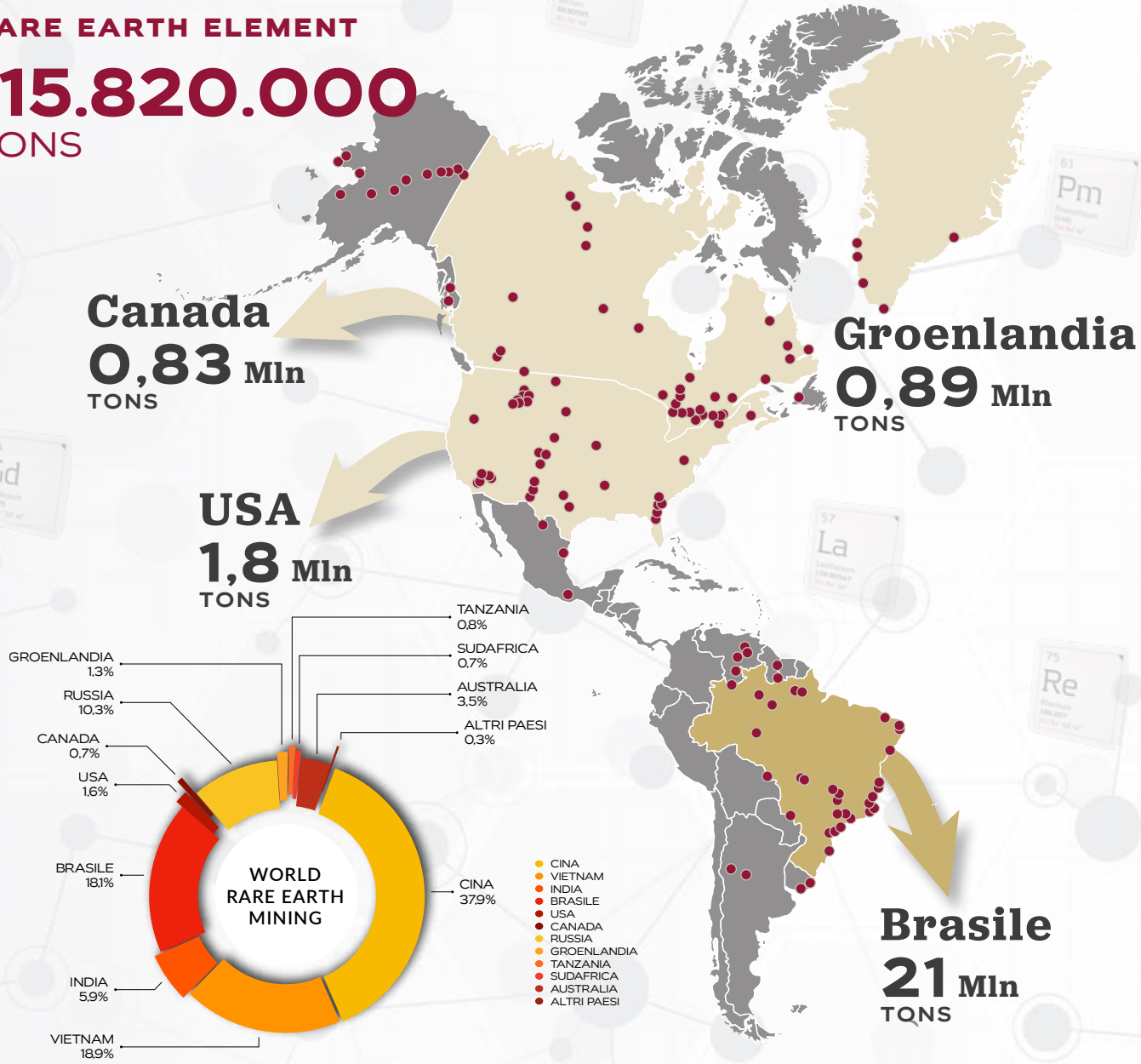
China's overseas expansion has also been crucial to maintaining its dominance: it has invested heavily in mining in Africa, Latin America and Central Asia, securing access to key raw materials beyond its borders. This international expansion has secured the supply chains that feed China's domestic industries, ensuring a steady flow of the raw materials needed to support technological and military advances. In addition, investment has tied resource-rich countries closely to China, often making them dependent on Chinese infrastructure and financing, and creating long-term debt.

In addition to economic expansion, China has used its control of REEs as a geopolitical tool. One of the most notable examples came in 2010, when it imposed a de facto embargo on rare earth shipments to Japan during a territorial dispute over the Senkaku Islands. This move not only highlighted China's willingness to use REEs as a weapon in geopolitical disputes, but also underlined the vulnerability of countries heavily dependent on Chinese imports. By exploiting its near monopoly, China can pressure other nations to align themselves with its political and strategic interests.

As demand for REEs continues to grow with the development of renewable energy technologies, electric vehicles and high-tech industries, China's strategic approach puts it in a powerful position. For countries such as the United States, Japan and members of the European Union, China's dominance in REEs poses a significant strategic challenge. These are nations that rely heavily on Chinese supplies to fuel their technological advances, making them vulnerable to supply disruptions in the event of geopolitical tensions. As a result, China's strategic approach not only secures its technological and military future, but also gives it considerable influence in global markets and international relations.

GLOBAL PRODUCTION RARE EARTH ELEMENT

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RARE EARTH

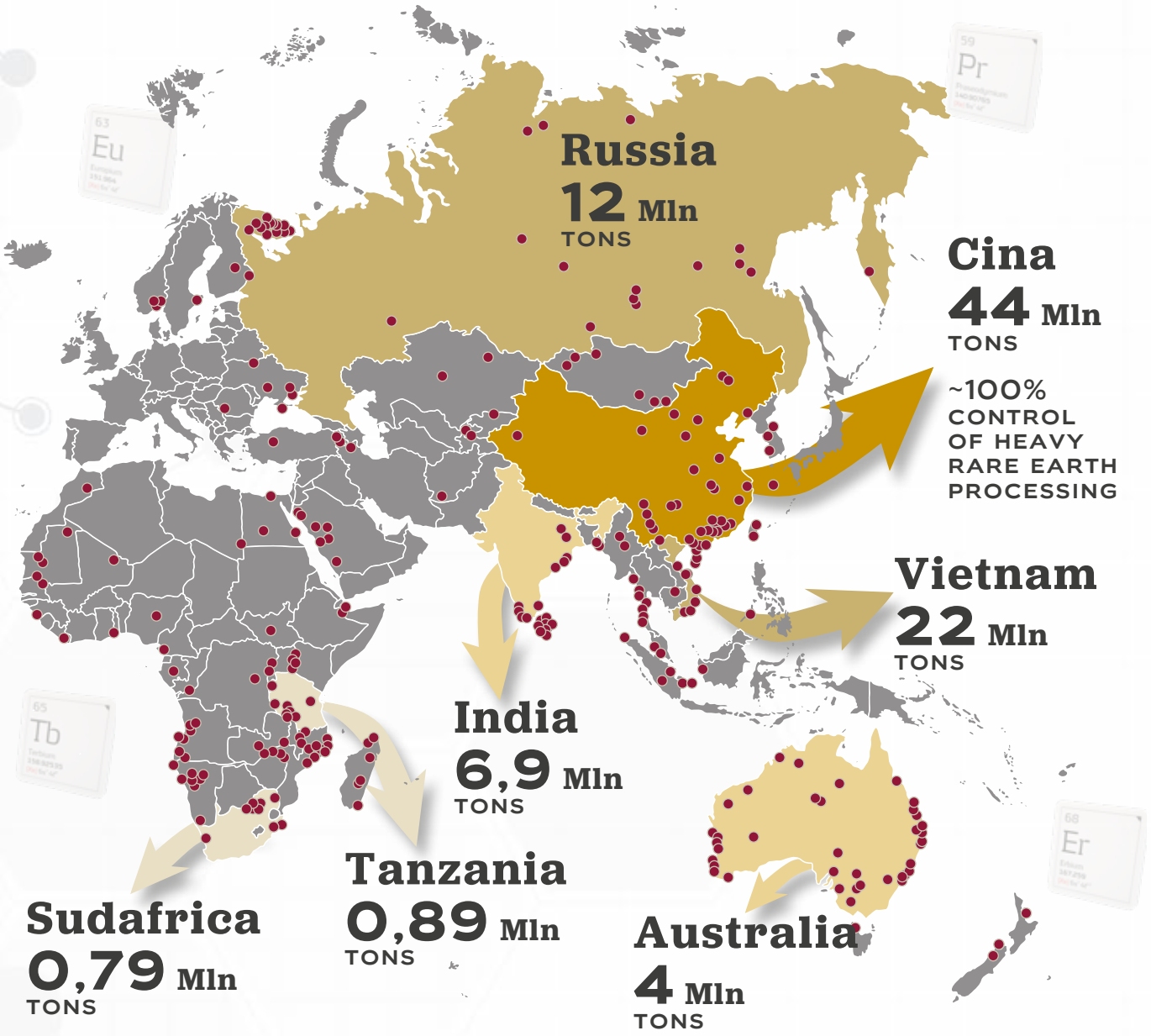
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CHEMICAL ELEMENTS

- Lantalio (La)
- Cerio (Ce)
- Praseodomio (Pr)
- Neodimio (Nd)
- Promezio (Pm)
- Samario (Sm)
- Europio (Eu)
- Gadolino (Gd)
- Terbio (Tb)
- Disprosio (Dy)
- Olmio (Ho)
- Erbio (Er)
- Tulio (Tm)
- Itterbio (Yb)
- Lutezio (Lu)
- Scandio (Sc)
- Ittrio (Y)

WHAT ARE RARE EARTH ELEMENT

- They are not true earths and they are not that rare, but they are fundamental metals for many modern technologies.
- They are used in consumer electronics, optical fibers, lasers, sensors, displays, catalysts, superconductors, permanent magnets, and in components of hybrid and electric cars.
- Their extraction is very polluting: for every ton of rare earths, up to 2,000 tons of toxic waste are produced.
- Recycling rare earths is very difficult: in electronic devices they are found in minimal quantities (mg), difficult to recover.
- A recycling chain would require large investments and a lot of time.



CHINA'S DOMINANCE

- China controls about 70% of all global extraction (270,000 tons out of 390,000 in 2024).
- It controls the processing of almost 100% of heavy rare earths, the most difficult to refine and most strategic.
- On April 4, 2024, Beijing imposed export restrictions on 7 heavy rare earths: samarium, gadolinium, terbium, dysprosium, lutetium, scandium, and yttrium. A special license is required, which is granted slowly, effectively blocking exports.

THE SITUATION IN EUROPE AND THE USA

- USA: The Mountain Pass mine in California mines light rare earths, not heavy ones. It has limited capacity.
- Europe: It has reserves (mainly in Scandinavia and Serbia), but activating new mines requires decades and major environmental and political choices.
- Many companies operate with minimal stocks to save money, which increases the risk in the event of a prolonged embargo.

Stati Uniti: giocare a nascondino

The United States, once the world's leading producer of REEs, has been playing catch-up in recent years. The closure of its main rare earth mine, Mountain Pass, in the early 2000s left the US dependent on imports, particularly from China, to meet demand for these critical materials. In recent years, however, the US government and industry have increasingly recognised the strategic risks posed by this dependence, particularly given China's dominance in the sector and the key role that REEs play in defence technologies and renewable energy.

One of the most significant initiatives taken by the US was the reopening of the Mountain Pass mine in 2017. However, the US continues to send raw minerals to China for refining, highlighting the continued US reliance on Chinese processing capacity, despite significant investment to expand domestic refining capacity, and recognising that reliance on foreign sources for these materials poses a national security risk. The United States faces significant challenges in achieving full independence from China. This dependence has led to increased government support, with the Pentagon funding rare earth projects to ensure access to critical materials needed for military technologies such as stealth and missile guidance systems, which are even more important in times of geopolitical tension.

In addition to domestic initiatives, the US has turned to international partnerships to diversify its supply chains. The US is working with allies such as Australia and Canada to secure alternative sources of REEs and critical raw materials. The aim of these partnerships is to reduce dependence on Chinese imports by drawing on the resources of trusted allies, thereby creating a more resilient supply chain that is less vulnerable to potential disruptions caused by geopolitical conflict or trade disputes.

Despite these efforts, significant challenges remain. Developing a fully independent REEs supply chain is a complex and time-consuming process. The United States does not yet have the refining capacity to process REEs domestically, which means it will continue to rely on Chinese infrastructure for the foreseeable future. In addition, the global nature of rare earth supply chains makes it difficult for any nation to achieve complete self-sufficiency. Until the US is able to address these issues, it will remain vulnerable to supply disruptions, particularly in the event of heightened tensions with China.

L'Unione Europea: obiettivi ambiziosi, vulnerabilità strategiche

The European Union, like the United States, faces significant strategic vulnerabilities due to its dependence on imports of REEs and other critical raw materials. Europe's ambitious targets for renewable energy, electric vehicle production and advanced manufacturing rely heavily on these materials, but the region has no significant domestic production. As a result, the EU has taken several steps to reduce its dependence on external sources, particularly China, and to ensure a more stable supply of critical materials.

One of the EU's key strategies is the creation of the European Raw Materials Alliance (ERMA). Launched in 2020, ERMA aims to strengthen the European supply chain for critical materials by supporting new mining projects in Europe and abroad, promoting recycling initiatives and developing partnerships with resource-rich countries such as Canada and Australia. ERMA brings together key stakeholders



from industry, academia and government to create a more resilient and sustainable critical materials supply chain.

Beyond mining, the EU has made sustainability a cornerstone of its strategy. Recognising the environmental and political challenges associated with traditional mining, it has invested in technologies to recycle REEs and other critical materials from end-of-life products such as electric vehicle batteries and wind turbines. By creating a circular economy around these materials, the EU hopes to reduce its dependence on primary imports while addressing concerns about the environmental impact of mining and resources. This approach not only helps to ensure a more sustainable supply of materials, but is also in line with the EU's wider environmental and climate goals.

International cooperation has also been a key

element of Europe's strategy to secure the supply of critical materials. The EU has sought to strengthen diplomatic and economic ties with countries that have significant reserves of REEs and other critical materials. In particular, Europe has focused on building relationships with resource-rich nations such as Australia, Canada and several African countries. These partnerships aim to ensure stable and diversified supply chains that are less vulnerable to geopolitical disruptions.

Despite these efforts, Europe's import dependence remains a significant vulnerability. Europe still imports the vast majority of the REEs and key commodities it uses from China, making the region highly vulnerable



to supply disruptions. In a scenario where geopolitical tensions escalate or China imposes export restrictions, Europe could face serious shortages of the materials needed to support the transition to renewable energy and advanced manufacturing.

Africa: Resource-rich but politically unstable

Africa has long been recognised as a key player in the global supply of REEs and critical raw materials. Major African countries have rich deposits of materials such as cobalt, lithium and tantalum, which are essential for modern technology, from electric vehicles to military applications. Key African players in this field include the Democratic Republic of Congo, South Africa and Madagascar, each of which has significant reserves of critical materials. However, despite its wealth of resources, Africa's ability to maximise its potential is often hampered by political instability, corruption and underdeveloped infrastructure.

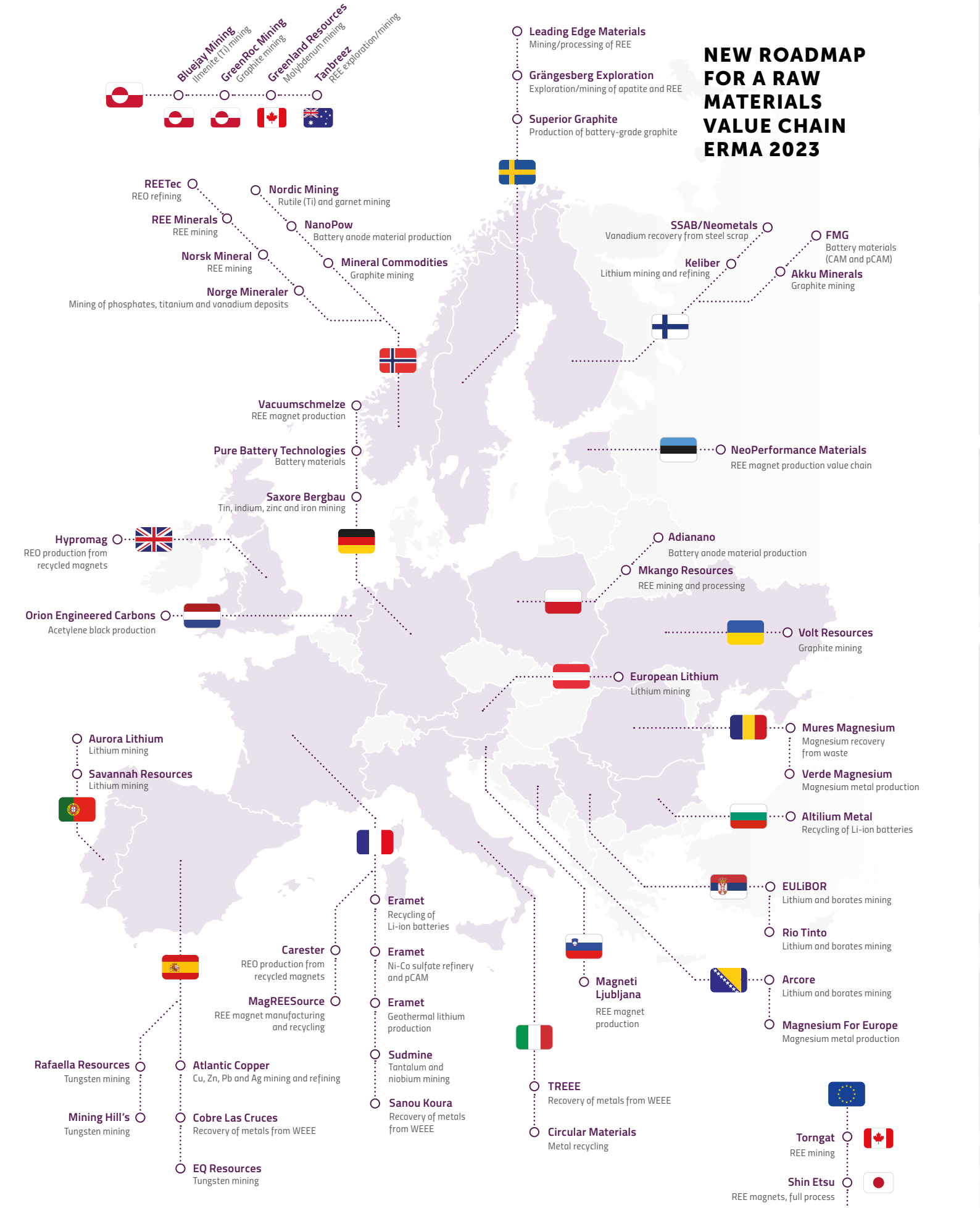
The *Democratic Republic of Congo (DRC)* stands out as the world's largest producer of cobalt, a key component in the production of lithium-ion batteries used in electric vehicles and renewable energy storage systems, making the DRC a key player in the global transition to clean energy. However, the country's mining industry faces a number of challenges, including political instability and corruption, which severely limit its ability to maximise its potential. Artisanal mining, which includes small-scale and often informal mining activities, is widespread in the DRC and raises concerns about human rights abuses, including child labour. Despite these challenges, the DRC remains a key player due to the huge volume of its cobalt production and is a major target for foreign investment, particularly from China.

South Africa is another key player in the African mining landscape, with significant reserves of REEs and other critical materials. However, like the DRC, South Africa's mining industry has faced its own challenges. Labour disputes, political tensions and a lack of modern infrastructure have hampered the country's ability to exploit its resource wealth. South Africa's REEs industry has the potential to make a significant contribution to the global supply chain, but requires further investment and modernisation to compete with global players such as China and Australia. However, the country remains strategically important due to its reserves and established mining infrastructure.

Madagascar, with its rich deposits of minerals such as graphite and REEs, has also emerged as a key player in the global supply of critical materials. However, like many African countries, it faces significant challenges related to political instability and underdevelopment. Chinese investment in Madagascar's mining sector has increased significantly in recent years, as China seeks to secure access to the island's rare earth deposits. This dynamic has raised concerns about the possibility of over-reliance on Chinese investment and control over Madagascar's resources.

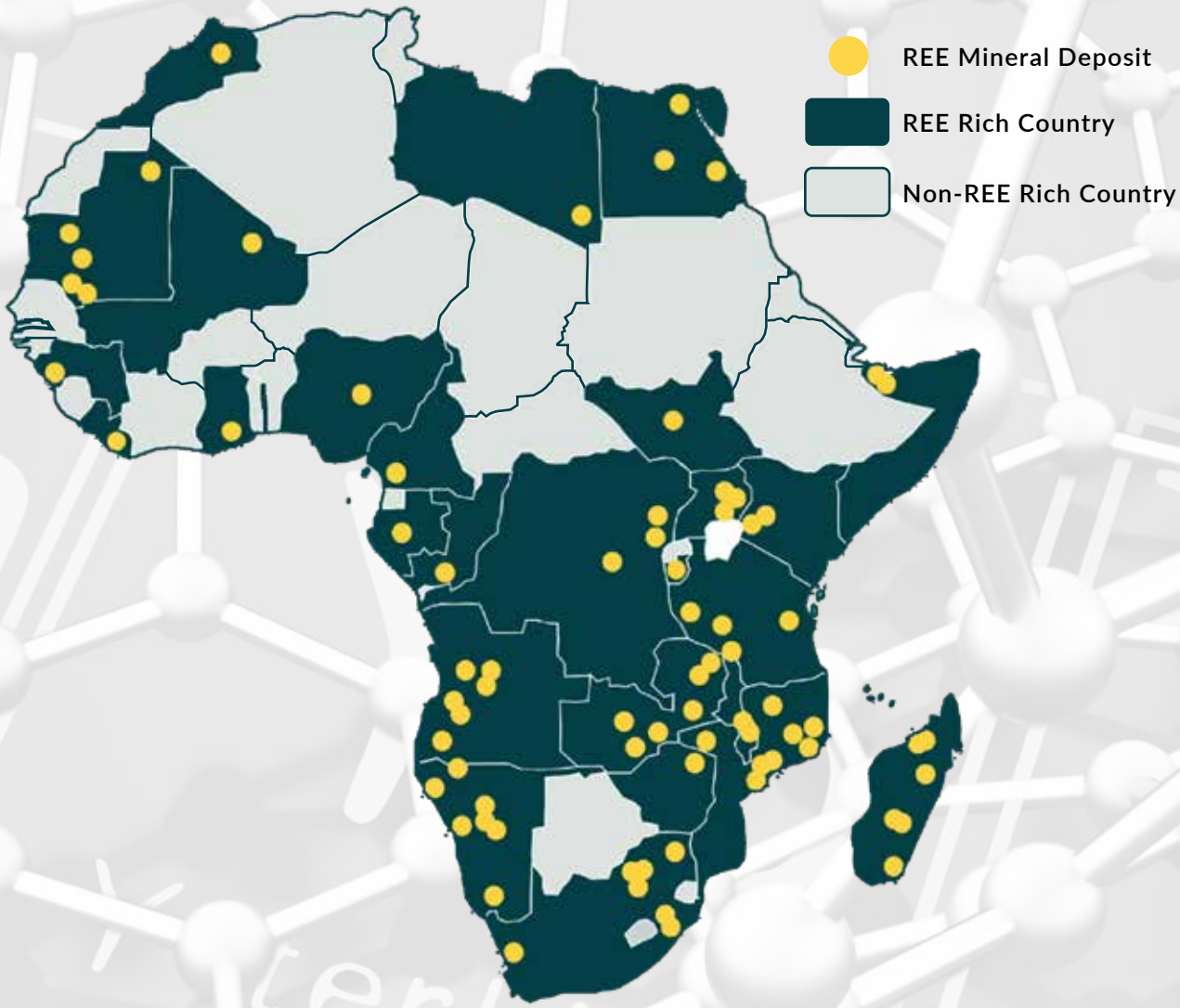
The geopolitical importance of Africa in the global scramble for REEs and essential commodities is undeniable. However, the region's political fragility, economic challenges and dependence on foreign investment, particularly from China, raise significant concerns about its ability to capitalise on its resource wealth. As global demand for these materials continues to grow, African countries will need to address these challenges in order to position themselves as reliable and stable suppliers in the global supply chain and still make a reasonable profit.

NEW ROADMAP FOR A RAW MATERIALS VALUE CHAIN ERMA 2023



Geographic distribution of current and potential raw materials projects identified through the ERMA investment pipeline. Some projects are not shown on this map for confidentiality reasons but are included in the ERMA supply data.

DISTRIBUTION OF REE DEPOSITS IN AFRICA



Source: U.S. Geological Survey



POTENTIAL FUTURE PLAYERS IN THE BATTLE FOR REES AND COMMODITIE

Russia: an emerging player??

While not a dominant player in the REEs market, *Russia* has vast reserves of critical minerals, including cobalt and lithium. As global demand for these materials continues to grow, Russia's strategic interest in exploiting its natural resource wealth is becoming increasingly clear. Russia's geopolitical position, combined with its historical use of energy resources as a foreign policy tool, suggests that it may adopt a similar approach to REEs and critical minerals in the future.

One of Russia's key strategic interests is to secure its technological independence. In recent years, it has come under severe pressure from Western sanctions, which have affected its economy and limited its access to foreign technology. As a result, it has expressed a desire to reduce its reliance on foreign technology and become more self-sufficient in critical sectors. Securing domestic sources of REEs and critical raw materials is essential to achieving this goal, as these materials are essential to the production of advanced technologies, including military hardware and consumer electronics.

Russia's military applications also drive its strategic interests in REEs. As a major military power, it relies on advanced technologies that require REEs, such as missile guidance systems, radar systems and jet engines. These materials are critical to maintaining the technological edge of Russia's military-industrial complex, especially as the country seeks to modernise its armed forces and expand its capabilities in both conventional and asymmetric warfare. Ensuring access to a stable supply of REEs is therefore a key component of Russia's national defence strategy.

Geopolitical leverage is another factor underpinning Russia's interest in REEs and essential commodities. The country has a long history of using its energy resources, particularly oil and natural gas, as foreign policy tools. For example, it has used its control over gas supplies to Europe as a means of exerting pressure on neighbouring countries and influencing political outcomes. It is conceivable that Russia could adopt a similar approach to REEs, especially as global demand for these materials continues to grow. By leveraging its resource wealth, Russia could gain greater influence in global markets and increase its bargaining power in international relations.

Russia's growing ties with China are also important in this context. As China continues to dominate the global REEs market, it may seek to secure additional sources of REEs from Russia. This dynamic could

further consolidate control over these critical materials, giving both Russia and China significant influence over global supply chains. Furthermore, as Western nations seek to reduce their dependence on Chinese imports, Russia could position itself as an alternative supplier, potentially using its resources as a geopolitical tool in its dealings with Europe and Asia.

India: a rising technological power

As a fast-growing technological power, *India* is becoming an increasingly important player in the global market for REEs and key commodities. With its booming technology sector, ambitious renewable energy targets and growing military capabilities, India has recognised the need to ensure a stable supply of these vital resources. Although India has some domestic reserves of REEs, its mining and refining capacity is still underdeveloped, and the country relies on imports to meet much of its needs. However, the Indian government has launched several strategic initiatives to reduce this dependency and strengthen its position in the global supply chain.

One of the most important is the development of a domestic REEs industry. The Indian government has announced its intention to invest in domestic mining and processing facilities in order to become more self-sufficient in the production of critical materials. India's defence sector, particularly its missile and radar systems, relies heavily on REEs, making the development of a domestic supply chain a national security priority.

In addition to domestic initiatives, India has sought to strengthen partnerships with key allies to secure access to REEs and critical raw materials. Australia, in particular, has emerged as a key partner in this regard. As one of the world's leading producers of REEs, it has become an important source of critical materials for India's growing technology and defence industries. By working with Australia and other resource-rich nations, India aims to diversify its supply chains and reduce its dependence on China, which, as noted above, currently dominates the global REEs market.

India's military modernisation efforts are closely linked to its strategic initiatives in the REEs sector. As India seeks to develop advanced defence technologies and modernise its military capabilities, securing a steady supply has become increasingly important.

Finally, India's broader geopolitical position in the Indo-Pacific region increases its strategic importance in the global competition for REEs and critical raw materials. As an emerging power in the region, India is well positioned to play a key role in shaping the future of the global supply chain for these materials. By investing in domestic production, strengthening international partnerships and modernising its military capabilities, India is positioning itself as a key player in the global competition for REEs and critical materials.

Latin America: The Lithium Triangle

Latin America, particularly the countries of Chile, Argentina and Bolivia, is home to some of the world's largest lithium reserves. This region, known as the 'Lithium Triangle', is becoming increasingly important as the world moves towards electric vehicles and renewable energy storage.

The Lithium Triangle is home to some of the world's largest reserves of the metal, which is critical for the production of batteries that are essential for electric vehicles, renewable energy storage systems and portable electronics. As global demand for electric vehicles and clean energy technologies has increased, the strategic importance of the lithium triangle has grown significantly, particularly as the shift to renewable energy and the electrification of transport create unprecedented demand. As countries around the world seek to phase out fossil fuels, demand has skyrocketed, making reserves in the lithium triangle a critical component of the global supply chain.

Both China and Western countries have expressed strong interest in securing access to the lithium triangle's reserves. Chinese companies have already made significant investments in mining activities in the region to secure a stable supply of the material for their fast-growing electric vehicle and renewable energy sectors. At the same time, Western countries, particularly the US and Europe, are seeking to establish partnerships with the Triangle countries to reduce their dependence on Chinese imports and secure a diversified supply.

The potential conflict over control of these resources underlines the geopolitical importance of the lithium triangle. As global competition intensifies, the region could become a battleground for influence between major powers. However, political instability in countries such as Bolivia and Argentina, superimposed on economic challenges, could further complicate efforts to secure access to the region's reserves. In addition, concerns over environmental degradation and the rights of indigenous communities have heightened regional tensions, adding another layer of complexity to the global competition for the precious metal.

The strategic importance of the Lithium Triangle will continue to grow in the coming decades due to its vast reserves and increasing global demand. Chile, Argentina and Bolivia will play a key role in shaping the future of the global lithium supply chain. However, the region's political instability, economic challenges and environmental concerns must be addressed to ensure a stable and sustainable supply of these vital materials.



GEOPOLITICAL RISKS AND FUTURE CONFLICT SCENARIOS

As demand for REEs and essential commodities continues to grow, competition for control of these resources is likely to intensify.
One of the immediate risks is the rise of resource nationalism, where countries with significant reserves of REEs and key commodities adopt policies to restrict exports in order to protect their domestic industries. Such actions could lead to trade wars and significant disruptions to global supply chains.

Scenario 1: China imposes restrictions to REEs exportse

In 2010, the world witnessed a stark demonstration of China's willingness to use its dominance in REEs for geopolitical advantage. During a territorial dispute with Japan over the Senkaku Islands, China imposed an unofficial embargo on rare earth exports to Japan. The move sent shockwaves through industries dependent on these critical materials, particularly Japan's high-tech and automotive sectors, which rely heavily on REEs for everything from smartphones to hybrid car batteries. Although the embargo was short-lived, it highlighted the vulnerability of countries heavily dependent on Chinese supplies of REEs.
If China were to impose similar restrictions on rare earth exports today, the consequences could be even more severe, given the growing global demand for these materials. The United States, Japan and the European Union, all of which rely on rare earth imports for their defence and technology industries, would face significant disruption. The renewable energy, electric vehicle and consumer electronics industries would be particularly affected, as REEs are critical to the production of wind turbines, electric motors and various high-tech components.
In response, affected countries could respond with trade measures such as tariffs or export restrictions on other goods, raising tensions and potentially leading to a wider trade war. In addition, countries could accelerate efforts to develop alternative supply chains, investing heavily in domestic mining and refining capacity or seeking new sources of REEs from countries such as Australia, Canada and African nations. Although these measures could reduce dependence on China in the long term, in the short

term such an embargo would likely cause significant economic and geopolitical instability.

Scenario 1: China imposes restrictions to REEs exportse

Africa, with its vast reserves of cobalt, lithium and rare earth elements, is becoming an increasingly important battleground in the global competition for critical materials. China, the US and Europe all have a vested interest in securing access to these resources, which are essential for the production of advanced technologies and military systems. As demand for these materials continues to grow, Africa could become a flashpoint for military conflict or proxy wars.

One potential flashpoint is again the Democratic Republic of Congo, which holds more than half of the world's cobalt reserves. As noted above, China has already established a strong presence in the DRC's mining industry, securing long-term contracts and investing in infrastructure to facilitate the extraction and export of cobalt, which has raised concerns among Western nations, particularly the US, that China's dominance of African resources could give it a strategic advantage in the global race for critical materials.

If tensions rise, the DRC and other resource-rich African countries could become the scene of military intervention or proxy conflicts as foreign powers seek to protect their access to these vital materials. For example, the United States could strengthen military ties with African nations through security cooperation agreements, providing training and equipment to local forces in exchange for preferential access to critical materials. Alternatively, regional conflicts could be fuelled by competition between Chinese and Western-backed factions, further destabilising an already unstable region. Such conflicts would not only have devastating humanitarian consequences, but could also disrupt global supply chains, causing shortages of critical materials and driving up prices.

Scenario 3: Environmental conflicts and rights of indigenous populations in Latin America

The extraction of lithium, cobalt and other critical materials often carries significant environmental costs, and Latin America is at the forefront of these tensions. As global demand for lithium increases, driven by the transition to electric vehicles and renewable energy technologies, the countries of the so-called lithium triangle have become major suppliers. However, mining activities in these countries have sparked conflicts with local indigenous communities concerned about environmental degradation and water scarcity caused by lithium mining.

In Bolivia, for example, indigenous groups have protested against plans to expand lithium mining in the Salar de Uyuni, one of the largest salt flats in the world. These communities claim that lithium mining will deplete local water reserves and damage the fragile ecosystems on which they depend. As competition for lithium intensifies, these protests could escalate into wider conflicts, attracting the attention of foreign powers with a vested interest in securing access to the region's resources.

Western nations and China, both of which rely on REEs for their electric vehicle industries, could find themselves indirectly involved in these conflicts, either through their investments in local mining companies or through diplomatic efforts to protect their access to critical materials. In the worst case, these environmental disputes could escalate into wider geopolitical conflicts as foreign powers seek to influence local governments and secure preferential access to lithium supplies. Resolving these conflicts will require a careful balancing act between environmental concerns, the rights of indigenous peoples and the growing global demand for critical materials.

Scenario 4: Cyber warfare against rare earth supply chains

In an increasingly digital and interconnected world, control over REEs and critical raw materials extends beyond the physical resources to the technologies and infrastructure that depend on them. As nations compete for access to these vital materials, cyber warfare could become an important tool for disrupting rival supply chains or gaining access to proprietary technologies for extracting or refining REEs.

In one possible scenario, a nation-state could launch a cyberattack on a rival's rare earth processing facilities. By targeting critical infrastructure, such as computer systems that control mining operations or refining processes, the attacker could disrupt the rival's supply chain and cause material shortages. This type of attack could have far-reaching consequences, affecting industries that rely on REEs, including renewable energy, consumer electronics and military technologies.

Such an attack could be particularly devastating if it targeted a country with limited domestic production capacity, such as the United States or Japan, both of which rely heavily on imports of REEs. In response, the targeted country could retaliate with its own cyberattacks or impose sanctions on the attacker, risking an escalation of tensions and a wider conflict. Furthermore, the vulnerability of global supply chains to cyberattacks highlights the need for increased cybersecurity measures and resilience in the REEs sector. Countries that are able to protect their critical infrastructure from cyber threats will have a significant advantage in the ongoing competition for REEs and critical materials.

MITIGATING FUTURE CONFLICTS: INTERNATIONAL COOPERATION AND INITIATIVES

While the potential for future conflicts over REEs and critical materials is significant, there are several strategies that nations can pursue to mitigate these risks and ensure a more stable and equitable distribution of these vital resources.

One of the most effective strategies is to **diversify global supply chains**. Currently, REEs production and refining is highly concentrated in a few key regions, particularly China, which controls a significant portion of the global market. This concentration of supply has created vulnerabilities for countries dependent on these materials, particularly in the event of geopolitical tensions or trade disruptions. Diversifying supply chains by developing new mining projects, promoting recycling initiatives and investing in alternative sources of REEs can reduce these vulnerabilities and ensure a more stable supply of critical materials.

The first step towards diversification is the development of new mining projects in previously under-exploited regions. Countries such as Australia, Canada and African nations have significant reserves of REEs and other critical raw materials, but these resources have not been fully exploited due to a lack of investment or infrastructure. By working with these nations to develop mining projects, countries currently reliant on Chinese imports can reduce their dependence on a single supplier. For example, Australia has become a major player in the global REEs market, with companies such as Lynas Corporation

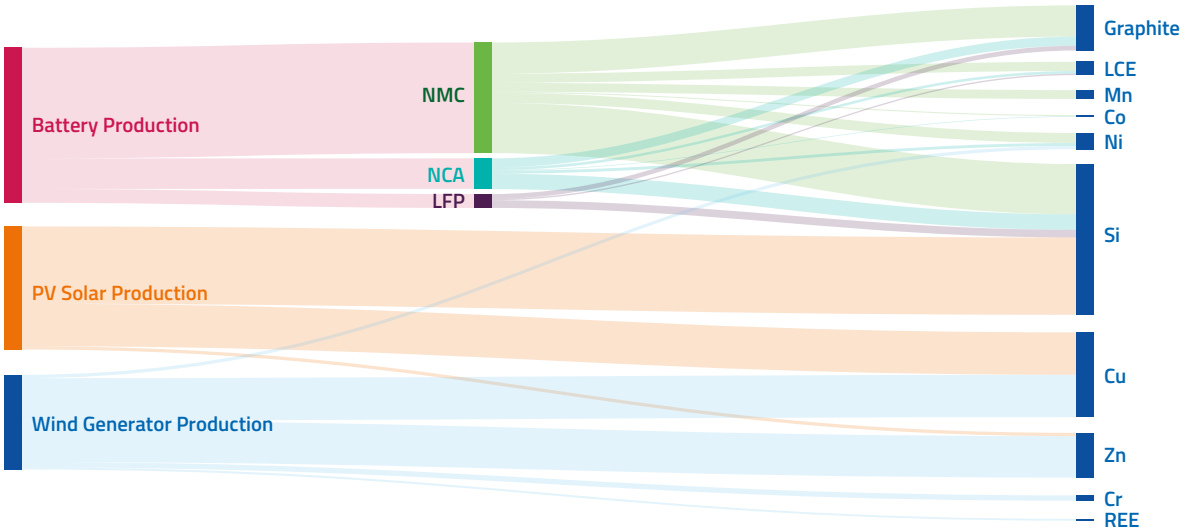
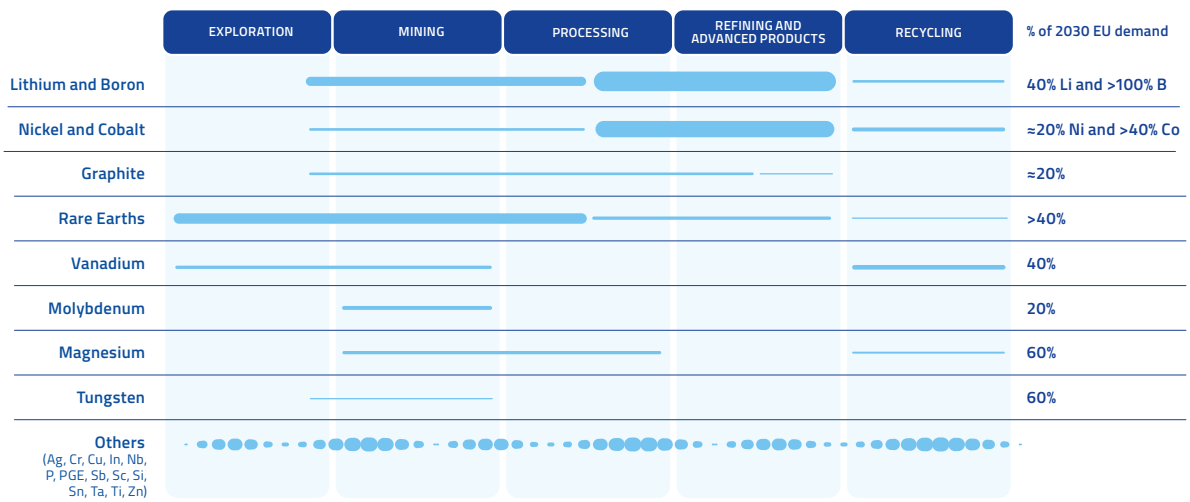
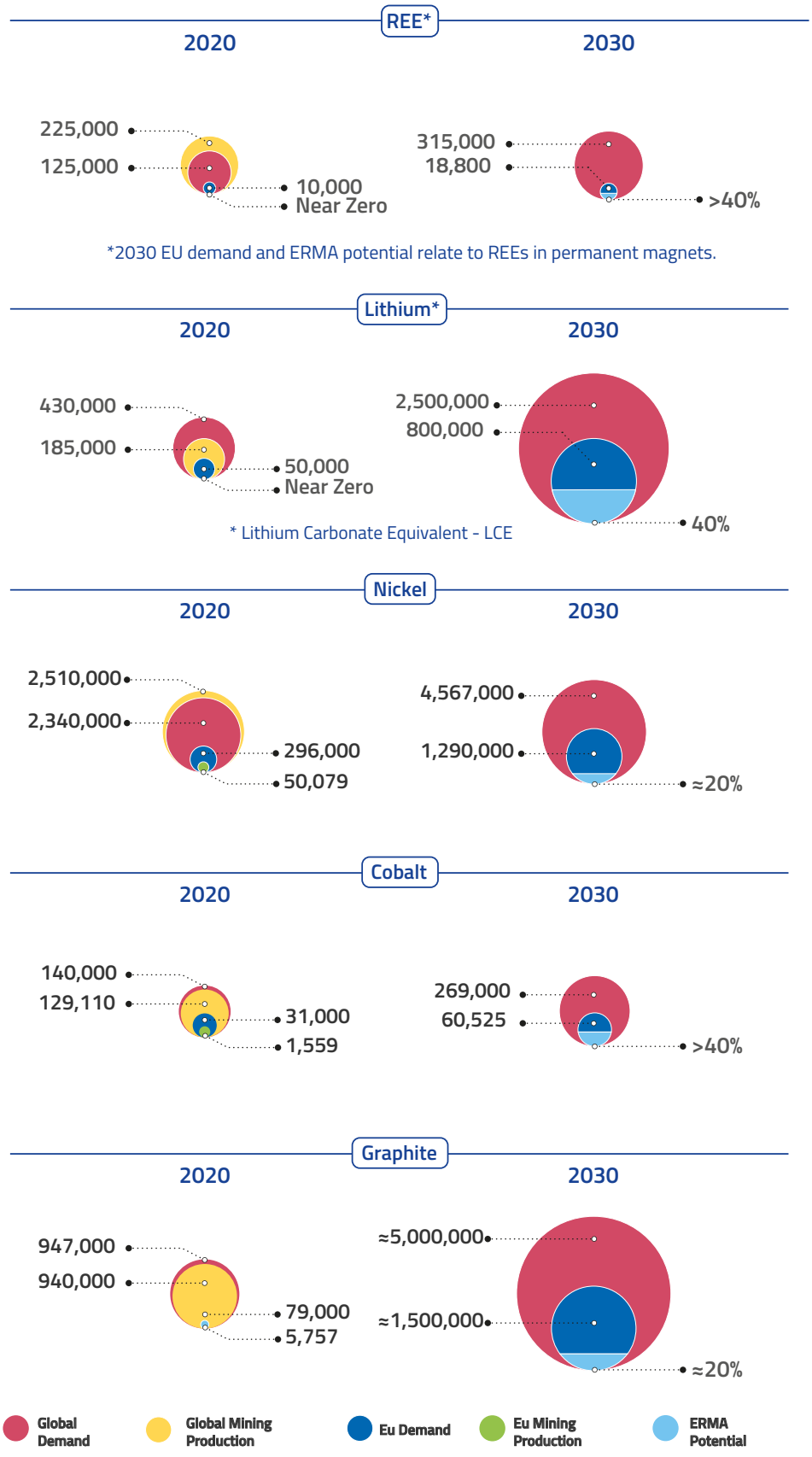


Figure 3. Link between technologies used for energy storage and conversion and raw materials needs, based on current assumptions regarding the energy mix and battery chemistries (NMC - Nickel-Manganese-Cobalt; NCA - Nickel-Cobalt-Aluminium: and LFP - Lithium-Iron-Phosphate). The need of raw materials for the production of batteries will be affected significantly by the market share of specific battery chemistry mixes.



NEW ROADMAP FOR A VALUE CHAIN ON RAW MATERIALS
ERMA 2023



Global and EU demand and production data for 2020, compared with projected global and EU demand for 2030 and potential supply from projects identified through the ERMA investment pipeline, for a selected group of critical and strategic materials. All figures are expressed in metric tons.

Source: World Mining Data and other EIT RawMaterials internal and external sources.

producing and refining REEs for export to the US, Japan and other countries. Increased investment in mining in Canada and African countries could further diversify global supply chains and reduce the risk of supply disruptions.

In addition to the development of new mining projects, **recycling** initiatives play a crucial role in diversifying supply chains. Many of the products that rely on REEs, such as electric vehicles, wind turbines and consumer electronics, have a limited lifespan, but the materials they contain can often be recovered and reused. By promoting the recycling of REEs from end-of-life products, countries can reduce their dependence on primary imports and create a more sustainable supply of critical materials.

The EU has committed €2.1 billion to projects such as RARE³, which recovers neodymium from hard drives and electric motors with 95% efficiency. Belgium's Umicore also recycles 200 tonnes per year of REEs from batteries and magnets.

Another important aspect of diversifying the supply chain is **exploring alternative materials** to replace REEs in key technologies. For example, an electric vehicle motor requires about 1-2 kg of rare earth magnets, while an offshore wind turbine uses up to 600 kg. Global demand for rare earth magnets could triple to 400,000 tonnes per year by 2030, but supply is not keeping pace, with a projected shortfall of 30-40% for elements such as dysprosium.

Research is therefore focusing on rare-earth-free magnets, as in the case of the US ARPA-E project, which has funded the development of ferrite and manganese alloy (MnAl-C) magnets with competitive performance at lower cost. The start-up company Niron Magnetics has developed an iron nitride (FeN) magnet with an energy density comparable to neodymium, which has already been tested by automotive companies. In the wind power sector, Siemens Gamesa has launched turbines with electrically excited generators (without permanent magnets), reducing the use of REEs by 100%. An example of this technology is the Kaskasi offshore wind farm in Germany.

Tesla has eliminated REEs from the motors of its "next-generation drive unit" by 2023, opting for ferrite magnets and induction systems (Tesla Master Plan Part 3). Toyota is also experimenting with reluctance synchronous motors combined with low-dysprosium magnets, reducing the use of REEs by 50 per cent.

Another practical example of these research initiatives is hydrolysis to produce green hydrogen: platinum catalysts can be replaced by nickel- and iron-based materials. Researchers at MIT have developed a cobalt-manganese oxide electrode that reduces costs by 70 per cent8. BASF has introduced platinum-free fuel cell catalysts using iron nanoparticles.

Despite progress, alternatives often require compromises in efficiency or cost. Ferrite magnets, for example, have a 30% lower energy density than neodymium, limiting their use in high-end applications. Furthermore, according to a report by the International Energy Agency, scaling up production will require infrastructure investment and a full transition could take 10-15 years.

Diversifying the supply chain requires a multi-dimensional approach: technological innovation, international cooperation and supportive policies. Countries such as the US and Australia are increasing domestic production of REEs, but reducing dependence will mainly come from alternative materials and circular models.

International cooperation is also essential to diversify supply chains. Countries with significant reserves of REEs and critical materials must work together to ensure that these resources are developed and distributed in an equitable and sustainable manner. By forming strategic alliances and partnerships, nations can share knowledge, resources and technologies to create a more resilient global supply chain. For example, the United States, the European Union and Australia have worked together to develop alternative sources of REEs and critical materials to reduce their dependence on Chinese imports. These partnerships have the added benefit of strengthening diplomatic ties and promoting cooperation in other areas such as trade, defence and environmental protection.

Ultimately, diversifying supply chains is a key strategy for mitigating future conflicts over REEs and critical materials. By developing new mining projects, promoting recycling initiatives, exploring alternative materials and fostering international cooperation, nations can reduce their vulnerability and ensure a more stable and equitable distribution of these vital resources. Although the path to diversification requires significant investment and innovation, it offers the most sustainable solution to the growing competition for REEs and critical materials in the 21st century.

Recycling and sustainable mining practices offer long-term solutions to the looming global shortage of REEs and critical raw materials. As demand for these materials continues to grow, particularly due to the increasing adoption of renewable energy technologies and electric vehicles, it is becoming increasingly clear that traditional mining alone will not be able to meet global demand. By investing in recycling technologies and adopting more sustainable mining practices, nations can reduce the environmental impact of resource extraction while ensuring a steady and reliable supply of critical materials.

Recycling is a key component of any sustainable strategy for REEs and critical materials. Many products that rely on these materials, such as electric

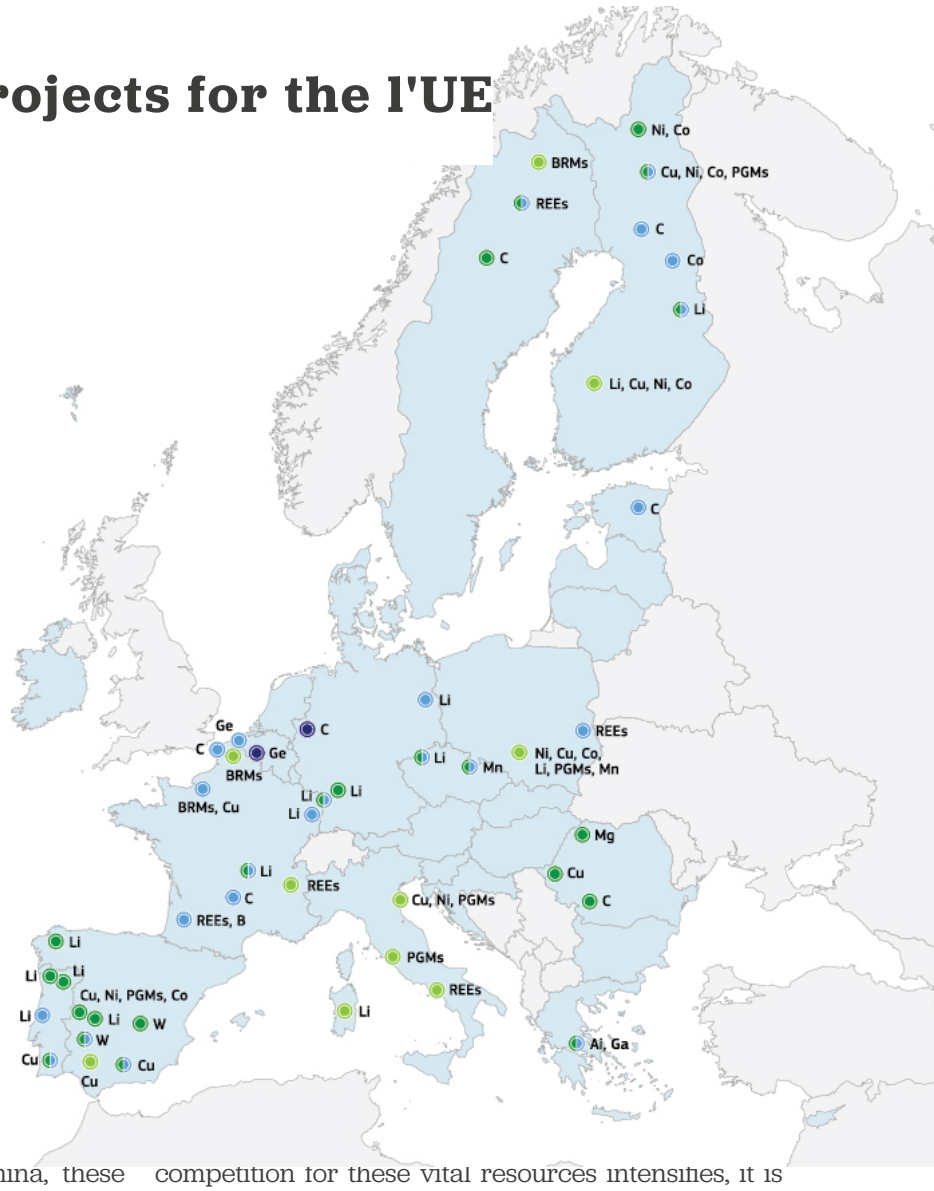
Strategic Projects for the l'UE

MAP LEGEND

Extraction
Processing
Recycling
Substitution

Al	Aluminium
B	Boron
BRMs	Battery Raw Materials [1]
Co	Cobalt
Cu	Copper
Ga	Gallium
Ge	Germanium
C	Graphite
Li	Lithium
Mg	Magnesium
Mn	Manganese
Ni	Nickel
PGMs	Platinum Group Metals
REEs	Rare Earth Elements
W	Tungsten

[1] *Battery Raw Materials refer to lithium, cobalt, nickel, manganese and graphite*



Disclaimer: The location of projects is based on a regional scale and doesn't reflect their exact geographical locations

and air pollution. In regions such as China, these environmental concerns have led to widespread protests and calls for stricter regulation. To address these challenges, mining companies and governments are increasingly focusing on adopting more sustainable practices that minimise the environmental impact of resource extraction.

One example of sustainable mining practices is the development of technologies that reduce the amount of waste generated during the extraction and processing of REEs. This includes innovations in extraction techniques such as the use of bioleaching, which uses naturally occurring bacteria to extract metals from ores in a more environmentally friendly way. In addition, the use of energy sources such as solar and wind power can help reduce the carbon footprint of rare earth mining. By adopting these and other sustainable practices, mining companies can minimise the environmental impact of their operations while ensuring a steady supply of critical materials.

Another important aspect of sustainable mining is the protection of local communities and ecosystems. In many cases, mining activities take place in remote

competition for these vital resources intensifies, it is becoming increasingly clear that cooperation among nations is essential to ensure a fair and equitable distribution of materials, to prevent resource-based conflicts, and to address the environmental and social challenges associated with resource extraction. By establishing international frameworks for the trade, production and management of REEs and critical materials, the global community can promote stability and reduce the likelihood of geopolitical tensions.

One of the key challenges in the global REEs market is the concentration of supply in a few countries, particularly China. China controls a significant proportion of the world's REEs production and refining capacity, giving it considerable influence over global supply chains. This dominance has led to concerns about the potential for supply disruptions, particularly in the event of geopolitical tensions or trade disputes. International agreements that promote fair and transparent access to REEs and critical materials are essential to reducing these risks. For example, agreements that set guidelines for trade in REEs, including restrictions on export bans or tariffs, can help ensure that all countries have access to the



materials they need to support their industries and economies.

The World Trade Organisation (WTO) has already played a role in regulating trade in REEs and critical materials. In 2014, the WTO ruled against China's restrictions on rare earth exports, finding that such measures violated international trade agreements. The ruling was an important step in ensuring that countries cannot use restrictions on rare earth exports as a tool to gain geopolitical advantage. This precedent underlines the importance of international trade institutions in maintaining fair access to critical materials. By establishing clear rules for REEs trade and resolving disputes through diplomatic channels, international organisations can help prevent conflicts that could result from supply disruptions or resource nationalism.

In addition to trade rules, international agreements focusing on sustainable mining practices and environmental protection are also crucial. As noted above, the mining and processing of REEs is often associated with significant environmental costs. To address these challenges, nations must work together to develop and implement international standards for sustainable mining. Agreements that promote cleaner mining techniques, minimise environmental degradation and ensure responsible management of natural resources can help reduce the environmental impact of REEs mining. For example, international environmental agreements such as the Paris Agreement can encourage countries to adopt greener mining practices and reduce the carbon footprint associated with the extraction of critical materials.

Another key area where international diplomacy can play a role is in protecting the rights of indigenous communities and local populations affected by mining activities. Many of the regions where REEs and critical materials are found are home to communities with long-standing cultural and economic ties to the territory in which they are located. The expansion of mining activities often poses a threat to these communities, leading to conflicts over land



rights, water use and environmental protection. International agreements that recognise and protect the rights of indigenous peoples are essential to ensure that resource extraction does not occur at the expense of vulnerable populations. For example, the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) provides a framework for protecting the rights of indigenous peoples in the context of resource development. By incorporating UNDRIP principles into international mining agreements, countries can help safeguard the rights of indigenous communities and promote more equitable resource management.

Countries with significant reserves of REEs and critical materials often face economic and political challenges that make it difficult for them to take full advantage of their resource wealth. International cooperation can help address these challenges by providing technical assistance, investing in infrastructure and supporting capacity building in resource-rich countries. For example, partnerships between nations, such as those promoted by ERMA, can facilitate the sharing of knowledge and expertise on sustainable mining practices, resource management and supply chain logistics. These partnerships can also promote the development of local industries and create economic opportunities for resource-rich countries, reducing their dependence on foreign investment and promoting more sustainable economic growth.

In addition to bilateral and multilateral agreements, international fora such as the United Nations (UN), the G20 and the International Energy Agency (IEA) provide platforms for dialogue on the global management of REEs and critical materials. These forums allow nations to share best practices, discuss emerging challenges and coordinate efforts to ensure a stable and sustainable supply of these vital resources. By engaging in diplomacy through these international institutions, countries can work together to address global challenges related to REEs, including supply chain vulnerabilities, environmental degradation and resource-related conflicts.

Ultimately, international agreements and diplomacy are essential to mitigate the risks of future conflicts over REEs and critical commodities. By establishing fair trade practices, promoting sustainable mining, protecting the rights of indigenous communities and fostering international cooperation, nations can ensure a more stable and equitable distribution of these vital resources. In doing so, they can reduce the likelihood of resource-based conflicts and promote a more sustainable and peaceful global economy.

In addition, **military diplomacy** plays a crucial role in shaping the geopolitical landscape around REEs and critical commodities, particularly as competition for these resources intensifies. As nations increasingly recognise the strategic importance of defence technologies, military diplomacy offers a way to manage tensions, secure access to resources and prevent conflict.

A key function of military diplomacy in this context is to promote alliances that secure critical materials for the defence industry. Through military partnerships, security agreements and joint exercises, nations can strengthen ties with resource-rich countries and gain access to critical raw materials in exchange for military assistance or defence cooperation. For example, the US and Australia have strengthened their military and diplomatic ties, resulting in increased access to Australia's REEs. Similarly, military cooperation with African countries such as the Democratic Republic of Congo can help secure the cobalt needed for advanced military technologies while ensuring the stability and security of mining operations.

In addition, military diplomacy can help protect critical infrastructure that produces and refines REEs. Working with allied nations, the military can help

defend mines, refineries and transport routes that are critical to the global supply chain. This cooperation can prevent disruptions caused by terrorist attacks, piracy or regional instability, ensuring a steady flow of materials needed for military production. In areas prone to instability, such as parts of Africa or Latin America, military presence and cooperation agreements can secure these goods, protecting both the security of the host nation and the interests of international stakeholders.

In conclusion, military diplomacy is crucial to securing access to essential raw materials, preventing resource-based conflicts and safeguarding supply chains. As REEs and critical materials continue to underpin advanced military technologies, the role of military diplomacy in maintaining global stability will become increasingly important.

One of the most promising strategies for mitigating future conflicts over REEs and critical materials is to **invest in alternative technologies** that can reduce or eliminate the need for these materials. As global demand for REEs continues to grow, particularly in sectors such as renewable energy, electric vehicles and high-tech manufacturing, there is growing interest in developing technologies that can replace REEs or use them more efficiently. By investing in research and development of alternative materials and technologies, countries can reduce their dependence on REEs and mitigate the risks associated with supply chain disruptions, resource scarcity and geopolitical tensions.

One area of active research is the development of alternative magnets that do not rely on rare earth elements, such as neodymium or dysprosium. Researchers are exploring the use of alternative materials, such as iron- or cobalt-based magnets, which could replace rare earth-based magnets in some applications.

In addition to alternative magnetic technologies, advances in materials science are opening up new possibilities. For example, scientists have long been exploring the use of graphene and other advanced materials in electronic devices, which could potentially replace REEs in some components. Graphene, a form of carbon arranged in a two-dimensional lattice, has exceptional electrical, thermal and mechanical properties, making it a promising candidate for a wide range of applications. By harnessing its potential, researchers hope to develop new technologies that can reduce the need for REEs while maintaining or improving performance.

Battery technology is another critical area where investment in alternative technologies could help reduce dependence on REEs and critical raw materials. Lithium-ion batteries, widely used in electric vehicles and renewable energy storage systems, require large quantities of lithium, cobalt and nickel, materials that are increasingly in demand and concentrated in certain regions. To address this challenge, researchers are developing alternative battery chemistries that can reduce or eliminate the need for these critical materials. For example, solid-state batteries, which use a solid rather than liquid electrolyte, offer higher energy density and greater safety than conventional lithium-ion batteries, while reducing reliance on cobalt and other critical materials. Similarly, researchers are exploring the potential of lithium-sulphur and sodium-ion batteries as alternatives to lithium-ion technology.

Another promising area of innovation is the development of energy-efficient technologies. Advances in electric motor design could reduce the amount of REEs needed to produce high-performance



motors used in electric vehicles and industrial machinery.

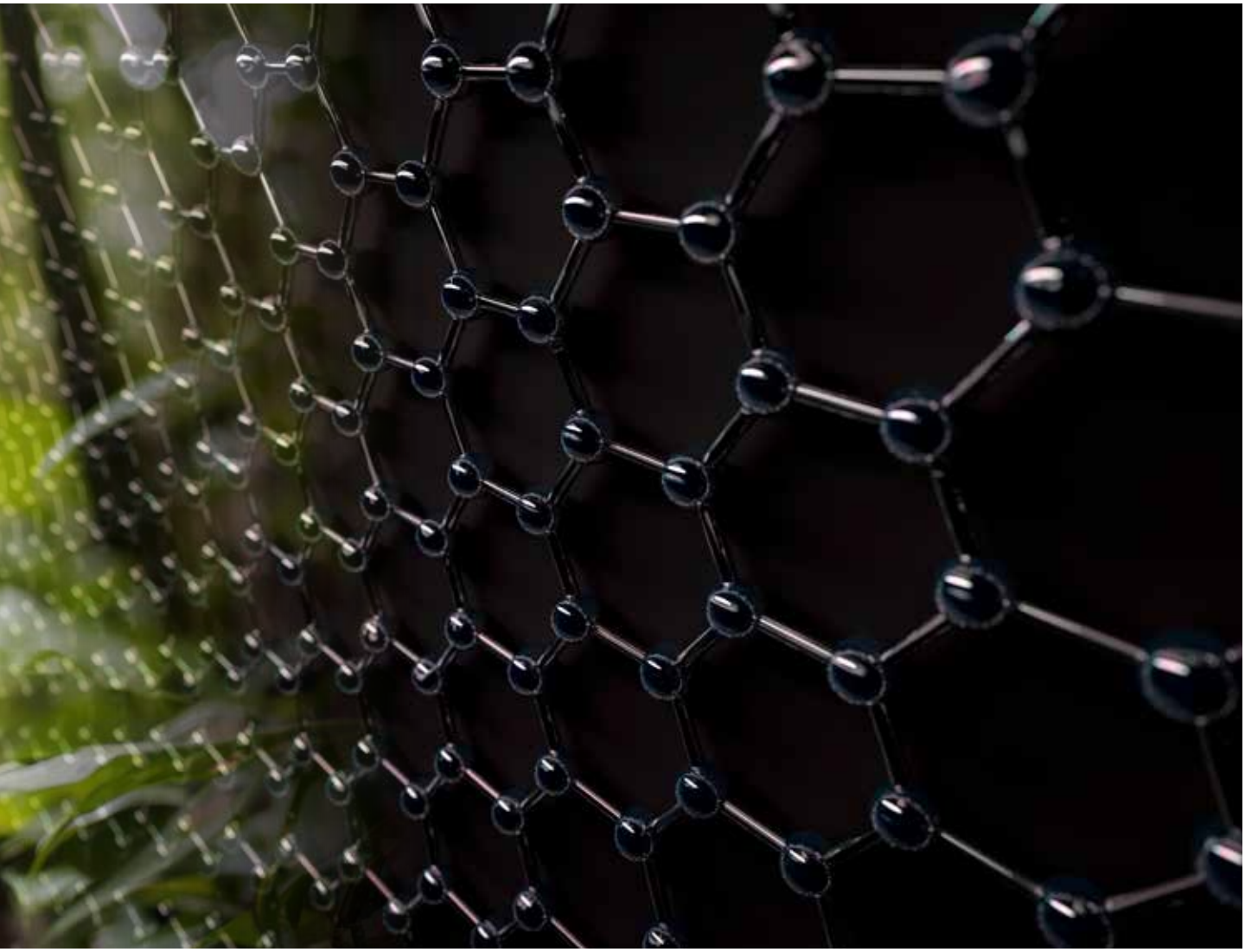
Investment in alternative technologies is not limited to the private sector; governments also play a crucial role in supporting research and development efforts through funding and policy initiatives. In the US, for

example, the Department of Energy (DoE) has launched several initiatives to support the development of alternative materials and technologies to reduce reliance on REEs. One of the key programmes is the 2021 Critical Materials Strategy, which covers a period up to 2031 and focuses on four key objectives for the energy and defence sectors, namely:

- Fostering scientific innovation and developing technologies that ensure resilient and secure mineral and critical materials supply chains, independent of extraction and processing by foreign adversaries.
- Catalysing and support private sector adoption and capacity for sustainable domestic supply chains of minerals and critical materials.
- Building a long-term minerals and materials innovation ecosystem that fosters new capabilities to mitigate future critical minerals and materials supply chain challenges.
- Coordinating with international partners and allies and other federal agencies to diversify global supply chains and ensure the adoption of best practices for sustainable extraction and processing.

The DoE is also funding the aforementioned research into alternative magnetic technologies based on iron or cobalt for use in electric vehicles and wind turbines. It is also supporting the development of solid-state and sodium-ion batteries. These efforts will help reduce Europe's dependence on imports, particularly from China, and ensure more sustainable supply chains for critical materials.

In conclusion, investment in alternative technologies is a key strategy to mitigate the risks associated with global competition for REEs and critical raw materials. By developing new materials, improving the efficiency of existing technologies and reducing dependence on scarce resources, countries can reduce their vulnerability to supply chain disruptions and geopolitical tensions. In doing so, they can promote a more sustainable and resilient global economy while addressing the environmental and social challenges associated with resource extraction.



CONCLUSIONS

The growing importance of REEs and essential commodities in civil and military technologies has transformed these resources into strategic assets with the potential to reshape global power dynamics. As nations become increasingly dependent on these materials for the production of renewable energy systems, electric vehicles and advanced military technologies, competition for access to these resources has intensified. The potential for resource-based conflict, whether through trade wars, military intervention or environmental disputes, has increased as countries scramble to secure stable supplies. Nations that control access to REEs and critical materials can gain significant technological and military advantages, while those that remain dependent on imports face increased vulnerability.

As demand for REEs continues to grow, particularly in the context of the global shift towards renewable energy and advanced technologies, the risk of geopolitical conflict increases. Resource nationalism, trade restrictions and the militarisation of resource-rich regions are some of the key threats that could disrupt global supply chains. For example, China's near monopoly in REEs production and refining has already created significant dependencies, prompting other nations to seek alternative sources and reduce their reliance on Chinese exports. The US, EU and other countries have recognised the strategic risks associated with this dependence and are taking steps to diversify their supply chains, but progress remains slow.

There are, however, sound strategies for reducing the risks of resource-based conflicts and ensuring a more stable and equitable distribution of critical materials. International cooperation plays a key role in these efforts, as nations work together to ensure access to REEs while promoting fair trade practices. For example, the World Trade Organisation has been instrumental in resolving trade disputes related to REEs, and its role could be expanded to address future challenges. Similarly, diplomatic efforts to promote partnerships with resource-rich countries can help diversify global supply chains and reduce vulnerabilities associated with dependence on a single supplier.

In addition to diplomatic efforts, investment in alternative technologies offers a promising solution. Research and development into materials that can replace REEs in key technologies, such as alternative magnets for electric vehicles, can reduce global dependence on these critical resources. Examples include projects to develop alternatives to REEs in electric motors, or the development of alternative battery technologies that use fewer critical materials, providing a sustainable path for industries dependent on lithium and cobalt. Recycling and sustainable mining practices are also essential to address the threat of resource scarcity. Countries such as Japan and members of the European Union are pioneering the development of technologies to recycle REEs from end-of-life products, reducing the need for new mining projects and minimising environmental impact. By creating a circular economy around these materials, nations can reduce their environmental footprint while ensuring a steady supply of critical resources for the future.

In conclusion, the future of REEs and critical raw materials will be determined by the ability of nations to meet the challenges of competition for resources and to seize the opportunities offered by technological innovation and international cooperation. Through diversification, investment in alternatives and diplomatic engagement, it may be possible to reduce the risks of resource-based conflicts and ensure a more stable, sustainable and equitable distribution of these vital resources.

