Christian Rook

WHAT ARE RARE EARTHS?

HOW THE USA, CHINA, UKRAINE, CANADA, AND GREENLAND ARE INVOLVED

19. April 2025

0. CONTENT

1. INTRODUCTION

Hardly a day goes by without new headlines—often confusing and difficult to interpret: Donald Trump launches a global trade war. China announces export controls on critical metals. **The United States** suddenly exerts pressure on **Canada** (its "51st state")—and brings up the idea of "buying" or "occupying" **Greenland**. A rare earth deal surfaces in conversations with **Ukraine**. What exactly is going on here?

When I encounter such news, I try not to remain at the surface. I ask the questions behind the questions:

- What really drives politicians like **Trump**, **Putin**, and **Xi Jinping**?
- What economic, political, or psychological interests shape their hidden agendas?
- What's truly at stake—beyond the headlines?

In many of these seemingly unrelated developments, a common denominator emerges: rare earth elements.
These inconspicuous metals are the invisible engine of our modern world—no electric vehicles, no wind turbines, no smartphones, no military technology without them. Control over their extraction and processing determines economic sovereignty, technological leadership, and geopolitical power.

This report starts right there. I asked myself:
What exactly are rare earths? Where are they found? Who mines and processes them? How are they used? And why have they suddenly become so politically relevant?

With this, I aim to show how dependent the West is on China today—why Canada, Greenland, and Ukraine have come into the strategic spotlight following U.S. moves—and how the next global crisis could be triggered by a supply cutoff of metals and oxides that most people have never even heard of.

I have compiled everything I could find on the topic of **rare earths** as of today. Unfortunately, the current political climate is so unstable that the situation could change again by tomorrow.
But the underlying facts remain: **Rare earths** are one of the most powerful geopolitical levers of our time.

2. WHAT ARE RARE EARTHS - REALLY?

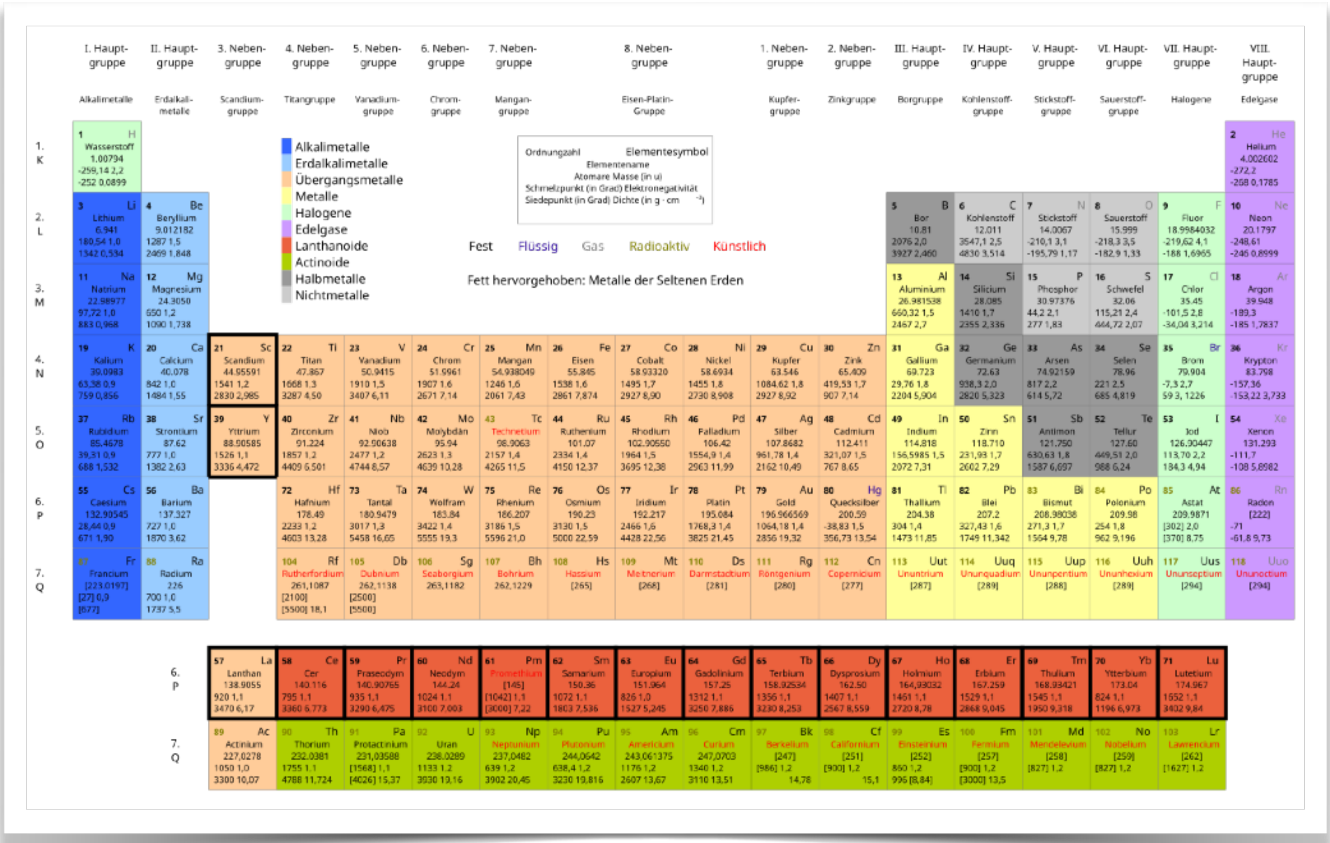
Rare earths—technically known as **rare earth elements (REE)**—are a group of **17 metallic elements** found in the periodic table. They include the 15 lanthanides, from lanthanum to lutetium (belonging to the third group of the periodic table), plus the elements scandium (Sc) and yttrium (Y). (See graphic 1)

Chemically, these elements are very similar due to their nearly identical ionic radii.

But why are they called "rare"?

Despite the name suggesting they are extremely scarce, many rare earth elements are not all that rare in Earth's crust. Cerium (Ce) and lanthanum (La), for example, are more abundant than lead or molybdenum.

They are considered "rare" because they are rarely found in concentrations high enough to be mined economically.



Grafik 1: Quelle: Wikipedia - die SEEs sind hier schwarz umrandet

> *„The commonly used term "rare earths" is somewhat misleading. The full and more accurate term is **rare earth metals** or **rare earth elements**. The expression "rare earths" dates back to the time when these elements were first discovered. They were initially found in rare minerals and extracted in the form of their oxides, which were historically referred to as "earths." In reality, only promethium—a short-lived, radioactive element—is truly rare in Earth's crust. Several of the rare earth metals —such as cerium (Ce), yttrium (Y), and neodymium (Nd)—are actually more abundant than lead, copper, molybdenum, or arsenic. Even thulium, the rarest stable rare earth element, is more common than gold or platinum." (Wikipedia)*

Typical host minerals include **bastnäsite** (a fluorocarbonate), **monazite** (a phosphate), and **ion-adsorption clays** found in southern China.

In bastnäsite and monazite deposits, nearly all rare earth elements typically occur closely together.

Depending on the geology of the deposit, extraction is carried out either via **open-pit mining** (as in China's Bayan Obo Basin or the Mountain Pass Mine in the USA), or by **leaching ion-adsorption clays** (in deposits located in China and Myanmar).

The **extraction and separation of rare earth elements** is one of the most complex challenges in metallurgy. Because the elements are chemically so similar, the ores must undergo **extensive processing**—often involving **hundreds of steps of liquid–liquid solvent extraction**—to isolate individual elements.

This refining process is highly energy- and chemical-intensive and produces hazardous or even radioactive waste, as in the case of monazite, which contains thorium.

As a result, rare earth processing requires **specialized expertise** and causes significant **environmental impacts**—which is why it still takes place **almost exclusively in China**.

Light Rare Earths vs. Heavy Rare Earths

The Elements of Rare Earths

LIGHT	HEAVY
Scandium (Sc) 44.96	Yttrium (Y) 88.91
Lanthanum (La) 138.91	Gadolinium (Gd) 157.25
Cerium (Ce) 140.12	Terbium (Tb) 158.93
Praseodymium (Pr) 140.91	Dysprosium (Dy) 162.50
Promethium (Pm) 145	Holmium (Ho) 164.93
Samarium (Sm) 150.36	Erbium (Er) 167.26
Europium (Eu) 151.96	Thulium (Tm) 168.93
	Ytterbium (Yb) 173.05
	Lutetium (Lu)

Of the 17 rare earth elements, 8 are classified as "light" and 9 as "heavy."

This distinction helps categorize their **occurrence, extraction, availability**, and **applications** more effectively. It is not based on strict chemical boundaries but rather on **atomic mass**, which plays a key role.

Light rare earth elements (LREEs) fall within an atomic mass range of **139–150 u** (*unified atomic mass units*).

Heavy rare earth elements (HREEs) range from 151–175 u.

Scandium and yttrium are an exception.

Light Rare Earths (Light Oxides)

Western producers primarily extract **light rare earths**. The USA and Australia, for example, mainly recover **lanthanum (La), cerium (Ce), neodymium (Nd),** and **praseodymium (Pr)** from **bastnäsite ores**. These deposits contain only minimal quantities of the heavier elements.

Heavy Rare Earths (Heavy Oxides)

Elements such as **dysprosium (Dy)** and **terbium (Tb)**, which are essential for high-performance magnets and other advanced technologies, are found almost exclusively in **ion-adsorption clay deposits** in **southern China**.
Some of this material also originates from **Myanmar**, where it is mined and then shipped to China for further processing.

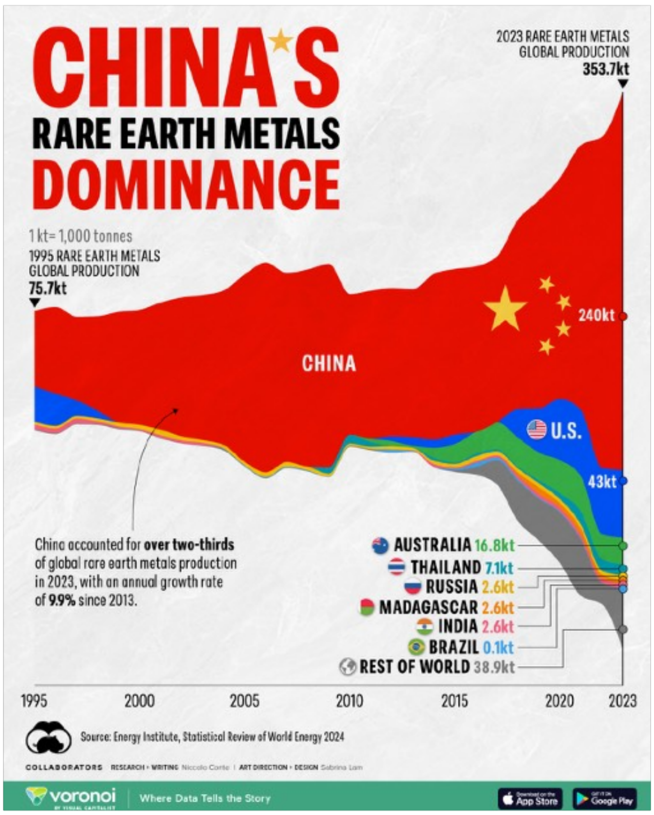
Other heavy rare earth elements include:
Erbium (Er), gadolinium (Gd), holmium (Ho), thulium (Tm), ytterbium (Yb), and lutetium (Lu).

In 2022, **China’s production quotas** reflected this divide clearly:

- Nearly 190,850 metric tons were allocated to light oxides,
- While only around **19,000 metric tons** came from **heavy oxides** sourced from ion-adsorption clays.

The Chinese dominance over **critical heavy rare earths** such as dysprosium and terbium is a **central geopolitical issue**.

3. GLOBAL PRODUCTION VOLUMES



China's Dominant Role in Rare Earth Production

The chart illustrates the sharp increase in global rare earth production since 1995 and its distribution across producing countries.

In **2023**, global rare earth output reached a **record high** of approximately **354,000 metric tons**—a dramatic rise compared to just **75,000 tons** in **1995**.

China further solidified its exceptional position as the world’s leading producer, with around 240,000 tons—accounting for roughly 68% of global production—coming from Chinese mines in 2023.

In **2022**, China's share stood at **approximately 70%** (210,000 tons out of a global total of 300,000 tons).

Other key producers in 2022 (though far behind China) included:

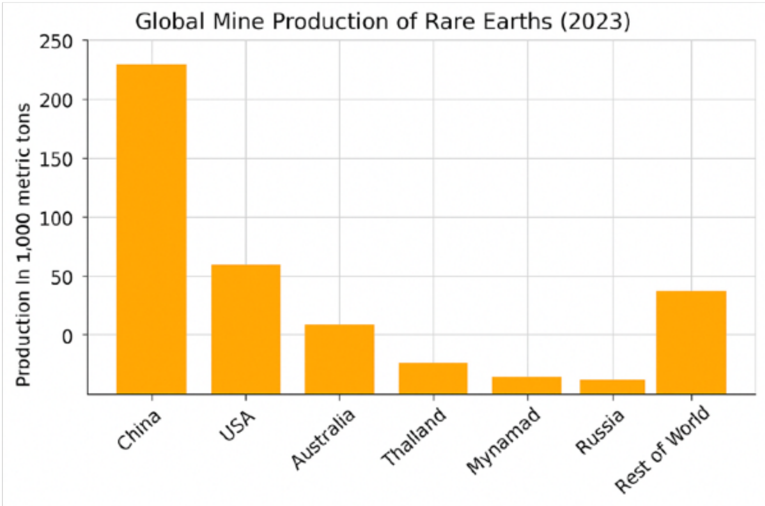
- The **USA** (Mountain Pass Mine, California): ~43,000 tons
- **Australia** (Mount Weld Mine): ~18,000 tons
- **Myanmar**: ~12,000 tons

Additionally, **smaller volumes** were extracted in 2022 by:

- **Thailand** (~7,100 tons)

- **Vietnam** (~4,300 tons)
- **India** (~2,900 tons)
- **Russia** (~2,600 tons)

By 2022, the combined share of all countries other than China had fallen to only 30% of global production (down from 42% in 2021).



Importantly, China not only **leads in volume** but also **dominates the production of heavy rare earth elements**, which are especially critical for high-tech applications. *(See Section 6 for details.)*

We will later explore untapped and dormant deposits in other countries.

China Is Dominating Rare Earth Metals Production

Global rare earth metals production has surged the past three decades, increasing from 75.7 kilotonnes in 1995 to over 350 kilotonnes in 2023, reflecting growing demand for these metals in high-tech applications.

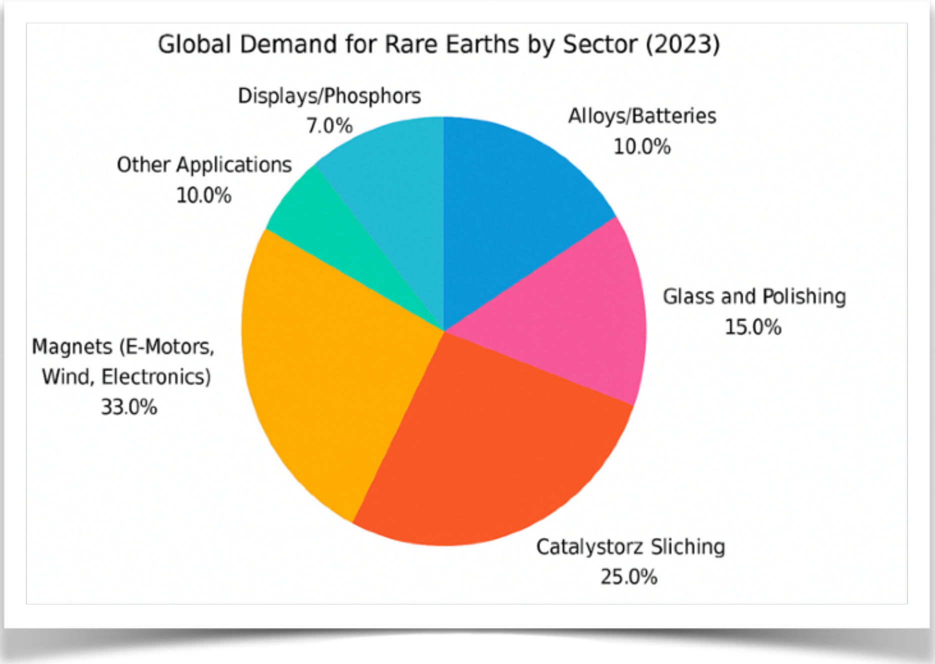
Country	1995 production (kilotonnes)	2005 production (kilotonnes)	2015 production (kilotonnes)	2023 production (kilotonnes)
Australia	0.1	n/a	11.9	16.8
Brazil	0.1	0.5	0.9	0.1
China	48	119	105	240
India	3	0.1	1	2.6
Madagascar	n/a	n/a	n/a	2.6
Russian Federation	1.7	2.2	2.3	2.6
Thailand	n/a	n/a	0.8	7.1
US	22.2	n/a	5.9	43
Rest of World	0.6	0.2	0.9	38.9
Total World	**75.7**	**121.9**	**128.6**	**353.7**

4. DEMAND BY INDUSTRIES

The demand for rare earth elements is distributed across a wide range of industrial sectors, reflecting their indispensable role in today's high-tech economy. In 2023, global consumption of rare earths reached approximately 350,000 metric tons, with a significant share driven by modern technology applications.

MAGNETS

One of the most important areas of use is in **permanent magnets**, which account for an estimated **33%** of total demand. These powerful magnets—primarily made from **neodymium**, often alloyed with **praseodymium**, **dysprosium**, or **terbium**—are essential for a broad spectrum of applications. In **electric vehicles**, they are used in the rotors of drive motors; in **wind turbines**, particularly in direct-drive systems, they are found in the generators; and in **consumer electronics**, they appear in everything from smartphones to headphones to hard drives. The global push for electrification and renewable energy is expected to further increase the demand for these magnet materials in the coming years.



CATALYSTS

Another major area of application is **catalysis**, which accounts for around **20 to 25%** of the total rare earth consumption. In **automotive catalytic converters**, **cerium oxide** and **lanthanum** play a key role as oxygen storage components, significantly enhancing the conversion of harmful exhaust gases. In the **petrochemical industry**, especially in **fluid catalytic cracking (FCC)** units used in oil refineries, large quantities of **lanthanum-based catalysts** are employed to break down heavy hydrocarbons into lighter, more valuable fuels like gasoline. Although these are older, more established technologies, they continue to consume vast amounts of rare earths—particularly **cerium** and **lanthanum**—and remain a major pillar of the global market.

GLASS/CERAMICS

The **glass and ceramics industries** represent another important sector. **Cerium oxide** is widely used as a polishing agent for **precision optics**, **mirror surfaces**, **silicon wafers**, and **flat screens**. **Lanthanum** contributes to the production of **high-refractive-index optical glass**, used in **camera lenses**, microscopes, and high-end optics. Meanwhile, **yttrium oxide** is critical for the manufacture of **high-temperature ceramics**, such as those used in jet engines or solid oxide fuel cells, and it serves as a **stabilizer** in **zirconium dioxide**, enhancing mechanical strength and thermal resistance.

Taken together, these applications highlight the strategic importance of rare earth elements across industries as diverse as **automotive**, **renewable energy**, **petrochemicals**, **electronics**, and **advanced materials**. The widespread use of these elements—often in small quantities but with no viable substitutes—makes their stable supply a key concern for industrial policy and global trade alike.

DISPLAYS

In addition to magnets, catalysts, and ceramics, **rare earths play a critical role in lighting and display technologies**. Phosphors made from **europium (Eu)** and **terbium (Tb)** are used in fluorescent lighting, while **yttrium (Y)** is a key component in **LED phosphors**. This sector was significantly larger in the past, particularly during the era of cathode ray tubes (CRTs) and fluorescent lamps. However, it has declined in recent years due to the widespread shift toward **LED technology**, which is more efficient and requires fewer rare earth materials overall.

SEMICONDUCTORS/ELECTRONICS

Another major consumer of rare earths is the **electronics and semiconductor industry**. Consumer electronics such as **smartphones, laptops**, and **headphones** contain **miniature magnets** in speakers, microphones, and hard drives, many of which are based on **neodymium alloys**. Displays and screens also incorporate various rare earth compounds to enhance color rendering and brightness. In semiconductor manufacturing, **cerium oxide** is used as a polishing compound for **silicon wafers**, while **rare earth dopants** are employed in **laser systems** and other high-precision processes.

DEFENSE

The **defense and aerospace sectors** are also heavily reliant on rare earth elements. High-performance magnets and lasers are critical for modern military systems, including **samarium–cobalt** and **NdFeB (neodymium–iron–boron)** magnets used in **precision-guided missiles**, **actuators**, **radar systems**, and **secure communications equipment**. **Neodymium–YAG lasers**, for instance, are used in **rangefinders** and targeting systems, where precision and reliability are paramount.

In summary, the **350,000 metric tons** of rare earths processed globally in **2023** were roughly distributed as follows:

- **33% for magnet applications**, including electric mobility, wind turbines, and electronics
- Approximately 25% for catalytic converters and petrochemical catalysts
- 10–15% for glass and polishing compounds
- **About 10% for metal alloys and batteries** (such as nickel-metal hydride batteries and specialty steels)

- The remaining share went to phosphors, ceramics, and other niche uses

These proportions are currently shifting **in favor of magnet applications**, driven by the global acceleration of **e-mobility and renewable energy** deployment.

The broad distribution of rare earth usage across such a wide array of sectors—from consumer goods to strategic defense—underscores their **fundamental importance to modern industry**. Far from being exotic materials for niche applications, rare earths have become essential building blocks of the 21st-century economy.

5. APPLICATIONS PER ELEMENT

The **17 rare earth elements** have vastly different usage profiles and production volumes. Two elements—**cerium (Ce)** and **lanthanum (La)**—dominate both extraction and consumption statistics.

Cerium and Lanthanum: The Bulk Elements

Both are **light rare earth elements** and occur in **particularly large quantities**. In typical bastnäsite ores, **cerium and lanthanum can together account for up to 80%** of the total rare earth content. Globally, they represent **more than half of total rare earth production volumes**.

Their widespread availability and relatively low cost (often below **$5/kg**) make them the "workhorses" of the rare earth sector. Cerium is primarily used in **catalytic converters** and **polishing powders**, while lanthanum is found in **refining catalysts**, **optical glass**, and **nickel-metal hydride (NiMH) batteries**. Both are consumed in **tens of thousands of tons per year**.

Neodymium: Technologically Critical

Close behind in importance is **neodymium (Nd)**. Although its share in rare earth ores is lower—typically **15–20%**—its demand is extremely high due to its role in **permanent magnets**. In 2022, China alone produced around **30,200 tons** of neodymium oxide, placing it among the top rare earths by volume. Neodymium is indispensable for electric motors, wind turbines, and electronics.

Praseodymium, Samarium, Gadolinium, Yttrium

Praseodymium (Pr), often used together with neodymium as "didymium", plays a similar role in magnet alloys. China's 2022 output was roughly **8,900 tons**.
Samarium (Sm) is used in **SmCo magnets** and as a **neutron absorber in nuclear reactors**, with annual volumes in the **low thousands of tons**.
Gadolinium (Gd) is used in **phosphors** and, most importantly, as a **contrast agent in MRI diagnostics**, though global volumes remain in the **hundreds of tons**.
Yttrium (Y), chemically classified as a heavy rare earth, has unique applications in **YAG lasers**, **ceramics**, and **phosphors**, with annual usage in the **low thousands of tons**.

The Truly Rare and Strategic Elements

The most **strategically critical** rare earths are found among the heavy elements—especially **dysprosium (Dy)** and **terbium (Tb)**. Although they account for **less than 5%** of total volume, they are **indispensable for high-performance magnets** and certain phosphors. In 2022, China produced just **6,100 tons of dysprosium oxide** and **1,100 tons of terbium oxide**, covering virtually **the entire global demand**, as few sources exist outside **China and Myanmar**.

Despite their small production volumes, these two elements are **vital**: without **dysprosium**, and to a lesser extent **terbium**, **neodymium magnets would lose their strength at elevated temperatures**. The **addition of 2–10% Dy or Tb** enables magnet use in high-heat environments like motors and generators. Terbium is also used in **green phosphors** for screens and fluorescent lighting, though demand in this segment is declining due to the rise of LEDs.

Limited supply and high geopolitical concentration make **dysprosium and terbium high-risk bottleneck elements**—with prices sometimes exceeding **$500/kg**. By comparison, cerium oxide trades for under **$5/kg**.

Niche Elements

Other rare earths—europium, holmium, erbium, thulium, ytterbium, and lutetium—are produced in very small quantities, typically under 100 tons annually worldwide.

- **Europium** was once essential for **red phosphors** in CRT televisions but has lost relevance in the LED era.
- **Holmium** and **erbium** are used in **laser systems** and **fiber optics**.
- **Thulium** and **lutetium** serve in highly specialized fields such as **medical radioisotopes** and **catalyst additives**.
  While **expensive**, their **macroeconomic impact is limited**, though they remain indispensable in defense, medicine, and aerospace.

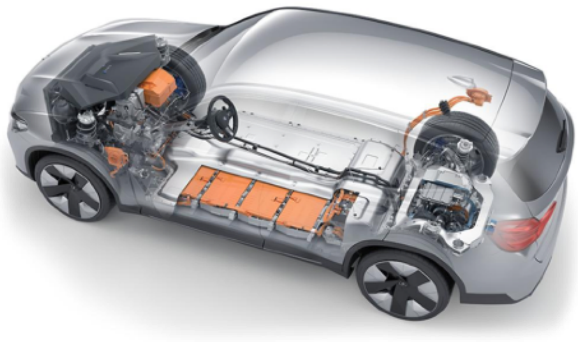
Element	Volume	Reserves	Price	Use Case Highlights	Strategic Risk
Cerium, La	Very High (>50%)	High	Low ($5/kg)	Catalysts, polishing, glass	❌ No
Nd, Pr	Medium	Medium	High	Magnets (EVs, wind, electronics)	✅ Yes
Dy, Tb	Low (<5%)	Low (China)	Very High ($500/kg)	High-temp magnets, phosphors	🔥 CRITICAL
Others	Very Low	Varies	Very High	Medical, lasers, niche defense/aerospace tech	⚠️ Moderate

6. APPLICATIONS IN KEY INDUSTRIES

To better illustrate their importance, let's look at some **concrete application examples** of rare earth elements in today's technologies:

Electric Vehicles (EVs) and Hybrid Cars

Neodymium (Nd) and **praseodymium (Pr)** form the core of **NdFeB permanent magnets**—the **strongest permanent magnets** in the world. These magnets are found in **nearly every electric vehicle**. A typical EV motor contains around **1 to 2 kilograms** of NdFeB magnet material, which translates to about **300 grams of neodymium/praseodymium**, plus a small amount of **dysprosium (Dy)**. Compared to older motor types, these magnets enable **more compact and lighter powertrains** with higher efficiency, directly increasing both the **range and performance** of electric cars.



Hybrid vehicles, such as the Toyota Prius, also rely on Nd magnets and additionally require significant quantities of **lanthanum (La)** in their **nickel-metal hydride (NiMH) batteries**—with a single battery containing **10–15 kilograms of lanthanum**.

Wind Turbines

In the **wind energy sector**, Nd magnets are equally transformative. **Modern direct-drive wind turbines** use high-pole-count generators based on **NdFeB magnets**, eliminating the need for heavy and maintenance-prone gearboxes. A single **3 to 5 MW wind turbine** can contain **hundreds of kilograms of Nd-Pr magnets**, along with **double-digit kilograms of dysprosium and terbium (Tb)**.

This design not only increases **efficiency** and **power density**, but also reduces **maintenance requirements**—a critical factor for **offshore installations**. Without these magnets, the **compactness and performance** of today's wind generators would be virtually impossible.

Sensors and Electronics

Rare earth magnets are also widely used in **sensor technology**. One example is the **Hall effect sensor**, found in cars and electronic devices for functions like **ABS braking**, **power steering**, and **positional feedback**. These sensors measure magnetic fields—often created by a tiny **NdFeB magnet** integrated within the sensor housing. Changes in the magnetic field caused by movement (e.g., speed or rotation) are registered as signals. This enables **precise, contactless measurement**—for example, in wheel speed sensors or smartphone compasses.

Hall Sensor - Source: TDK-Micronas

The Role of Dysprosium

In all these magnet-based technologies, **dysprosium** acts as a crucial but often invisible enabler. It is typically added in **5–10% concentrations** to NdFeB magnets in **EV motors** and **wind turbines** to ensure

thermal stability. Electric motors can reach temperatures of **150°C or more**, at which point pure NdFeB magnets begin to lose their magnetic strength. When alloyed with **dysprosium and terbium**, the magnets retain their performance even under high thermal loads. In wind turbines that operate continuously, dysprosium plays a similarly critical role in **maintaining reliability**.

Although engineers strive to **reduce dysprosium content** through improved cooling or innovative alloying techniques—mainly because **dysprosium is extremely expensive**—its unique function **cannot be fully replaced**.

Other High-Tech Applications

Beyond magnets, there are many additional examples:

- **Nd:YAG lasers** are high-power lasers used in **industrial machining**, **medical surgery**, and **military rangefinding**; here, neodymium is the active lasing medium embedded in a **yttrium aluminum garnet (YAG) crystal**.
- **Gadolinium (Gd)** is used in **MRI scanners** as a contrast agent.
- **Europium (Eu)**, once essential for **red phosphors** in CRT televisions, still plays a role in display technologies.
- **Erbium (Er)** is used to **dope fiber optic cables**, enabling signal amplification in **long-distance telecommunications**.

These examples make it clear: **rare earth elements—especially neodymium, praseodymium, and dysprosium—are critical functional materials** at the heart of electric motors, wind turbines, precision sensors, and countless high-tech systems that define both **our daily lives** and **modern industrial progress**.

7. GEOSTRATEGIC ASPECTS

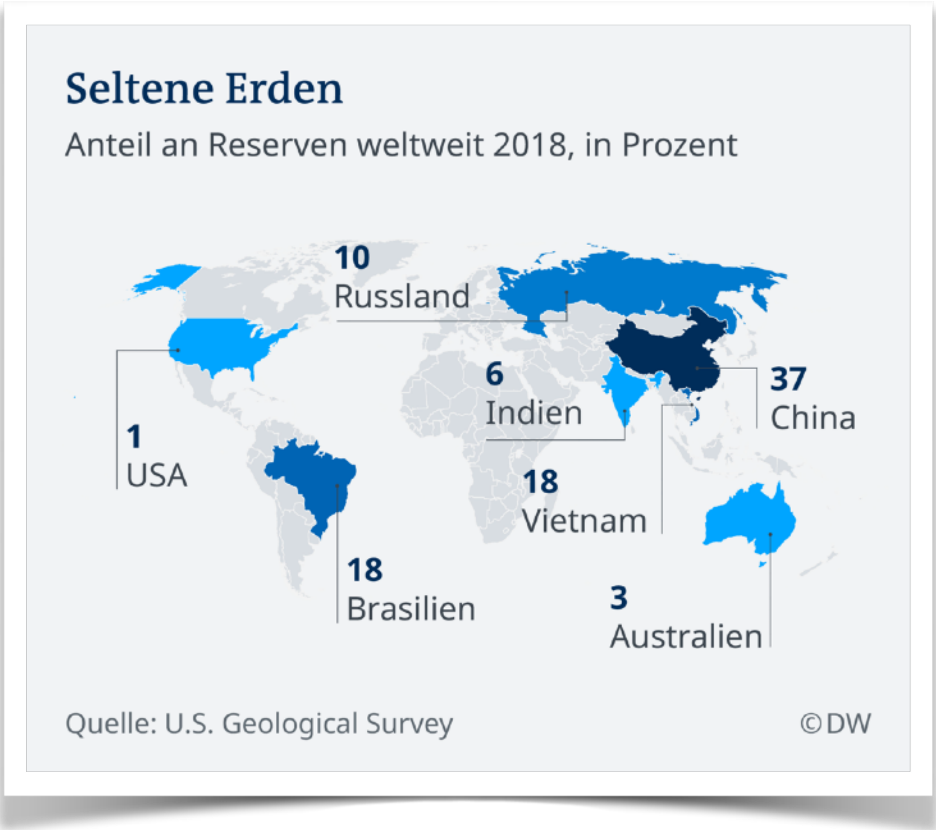
China's near-monopoly on rare earths gives the country significant geopolitical leverage.
This became strikingly clear as early as **2010**, when China curtailed rare earth exports to Japan during a territorial dispute over the Senkaku Islands. The supply volume dropped by about **40%**, sending prices **skyrocketing** overnight. Japan was forced to scramble for alternative suppliers to shield its **high-tech sectors**—particularly electronics and automotive manufacturing—from material shortages. Officially, Beijing cited **environmental regulations** at the time, but the **political message** was unmistakable: China is capable of **using its raw materials dominance as a strategic tool**.

Today, against the backdrop of the **US–China technology rivalry**, this issue is more pressing than ever. In **July 2023**, China announced new **export controls on gallium and germanium**—two minor metals essential for semiconductor production. Analysts interpreted this as a **retaliatory move** in response to U.S. sanctions against Chinese chipmakers.

This immediately triggered concerns that **rare earths could be the next target**—especially since China's dominance in this sector is even more pronounced.

On **April 14, 2025**, China **officially halted all rare earth exports to the United States**, marking a dramatic escalation. Within **two months**, this move is expected to **paralyze production** of electric vehicles, wind turbines, military electronics, and numerous other critical technologies.

Europe and Japan would also be severely affected, as they remain indirectly reliant on Chinese rare earths—even when sourcing through intermediates or finished products. Making things more difficult, **China controls around 85% of the world's rare earth processing capacity**. Even if raw concentrates were mined elsewhere, **they would still have to be sent to China for separation**—a dangerous bottleneck.



Rare Earths: Percentages of Rare Earth Reserves (2018)

Western security experts increasingly view rare earths as a potential economic "weapon" in a trade war.

To counter this, the West is attempting to **rebuild its position**. The **U.S. has officially designated rare earths as critical minerals** and is investing in the development of **domestic supply chains**. The **Mountain Pass mine** in California has been reactivated. Although ore processing still takes place in China, a dedicated U.S. separation facility is in the works.

With support from the U.S. Department of Defense, companies like Lynas (Australia) and MP Materials (USA) are constructing new refining plants in Texas and California. In addition, the Pentagon is building up a strategic stockpile of rare earth materials.

In **2023**, the European Union adopted the **Critical Raw Materials Act**, aimed at accelerating **domestic mining, recycling**, and the **development of substitute materials**. Estonia already hosts a rare earth **separation plant** (Silmet), which produces small volumes of oxides from imported concentrates.

Sweden announced a major rare earth discovery in the Kiruna region in 2023, though full-scale extraction is at least a decade away.

Japan, having learned from the 2010 shock, has diversified its supply with impressive discipline. Since 2013, through a joint venture with **Lynas**, Japan sources much of its magnet feedstock from **Australia and Malaysia**. It has also created **a government-run strategic stockpile** (covering several months' supply) and is investing in **recycling technologies** (e.g., rare earth recovery from e-waste) and **substitute materials**. These efforts are starting to bear fruit: the share of U.S. rare earth imports coming from China **dropped from 80% (2014–2017) to around 74% (2018–2021)**. However, true supply chain independence is still years away.

The war in Ukraine has also indirectly reshaped the West's raw materials strategy. The conflict has served as a stark reminder of the **risks of one-sided dependencies**—as seen with Europe's reliance on Russian natural gas. This has acted as a **wake-up call**, adding urgency to diversification efforts for rare earths and other critical materials.

Moreover, both **Russia and Ukraine** themselves are **potential suppliers** of rare earths and other critical minerals. Russia holds an estimated **21 million tons of rare earth reserves** (ranking third globally) and had plans to develop major deposits like **Tomtor** in Siberia. But sanctions and diplomatic isolation have made international cooperation impossible.

Ukraine also holds **relevant deposits** but is unable to develop them due to the ongoing war.

Meanwhile, **China has drawn closer to Russia**—including in **resource trade**—raising concerns in the West about **growing dependencies on authoritarian regimes** across the strategic materials supply chain.

Bottom line:
The war in Ukraine has underlined the **security dimension of critical raw materials**. It is **accelerating Western efforts** to reduce vulnerability in the rare earths sector—so that in a future crisis, access to these key resources cannot be weaponized.

8. STOCKPILES AND INVENTORIES

On **April 14, 2025**, China imposed a **full export ban on all rare earth elements to the United States**.

The move sent immediate shockwaves through global supply chains and has triggered urgent discussions across industries and governments. While the restriction currently targets only U.S. recipients, the ripple effects are being felt worldwide.

This scenario—long discussed as a geopolitical possibility—has now become reality. And the truth is sobering: **Western industries are not prepared.**

No Room to Maneuver

Most manufacturers that rely on rare earths—whether for **magnets**, **catalysts**, **batteries**, or **phosphors**—run on **just-in-time supply chains**, holding only a few **weeks or months' worth of stock**.
Strategic reserves in the West are limited or only now being built up. As of late 2022, the **U.S. National Defense Stockpile** held just **0.2 tons of dysprosium**—nowhere near what's needed to support sustained industrial output.

Although the U.S. has approved future acquisitions (e.g., 600 tons of neodymium and 1,300 tons of lanthanum), those purchases have not yet materialized in practice. **Japan** is better prepared, maintaining a national stockpile designed to cover **up to six months** of demand, but even that is vulnerable in a prolonged disruption.

The Countdown Begins

With China now out of the picture—at least for U.S. buyers—the clock is ticking. Once existing inventories of NdFeB magnets, catalyst powders, and rare earth oxides are depleted, production lines for electric vehicles, wind turbines, consumer electronics, and defense systems will begin to slow down—or shut down entirely.

The expected short-term fallout includes:

- **Explosive price spikes**, similar to the 2010 crisis, when prices for some oxides increased tenfold in just a few months
- **Global stockpiling behavior**, as every available ton outside China is snapped up
- **Strategic rationing**, with governments prioritizing defense, infrastructure, and critical industries

We may also see a rise in **illegal mining and smuggling**, as happened in **Baotou** during the last supply crisis. Desperate times breed black markets.

Emergency Measures

In the U.S. and allied nations, governments are now likely to:

- Release what little strategic reserves exist
- Implement state-led allocation of remaining stock to priority sectors
- **Accelerate imports from non-Chinese sources** (e.g., Australia, the U.S. itself, parts of Africa and South America)

- Intensify recycling programs (especially from e-waste)
- Fast-track development of refining capacity and substitution research

But There's a Bottleneck

Even if other countries increase mining output, the real chokepoint lies in processing capacity. China still controls around 85% of global refining and separation infrastructure.

- The **Mountain Pass mine** in California and **Lynas's Mount Weld** operation in Australia may boost production marginally—but they are close to capacity.
- **New projects** in Africa and the Americas could become viable as prices soar—but they need time.
- The only major rare earth separation plant outside China, run by Lynas in Malaysia, may help, but its capacity is limited.
- The **MP Materials refinery** in the U.S. is **not expected to be operational before late 2025**, and European projects are still in early phases.

Realistic Timeline

- **Short-term (0–2 years):** Substantial shortages are likely. Full substitution of Chinese supply is **not possible**.
- **Mid-term (3–5 years):** Existing mines may ramp up, new brownfield sites might come online, and recycling efforts can grow—but gaps will remain.
- **Long-term (5–10 years):** With massive investment, policy support, and coordinated strategy, a **non-Chinese rare earth supply chain may finally be viable**—but it will take time.

Conclusion: Strategic Vulnerability Laid Bare

China's move to halt rare earth exports to the U.S. has **transformed a theoretical risk into a live geopolitical crisis**. Western industries—particularly in the energy, mobility, and defense sectors—are facing **severe exposure**. Supply chain resilience, long overlooked in favor of efficiency, has now become a strategic imperative.

This isn't just about minerals. It's about **economic sovereignty**, **national security**, and the ability to **withstand pressure in a multipolar world**.

9. WHAT ARE THE ALTERNATIVES?

Substitution and Reduction: Can We Do Without Rare Earths?

In light of current supply risks, one key question arises: Can rare earth elements be substituted or avoided altogether?

The answer is yes—but only to a limited extent.

For many applications, alternative materials exist, but they typically come with **trade-offs in performance, size, efficiency, or cost**.

Magnets: Limited Alternatives

Take **NdFeB permanent magnets**, for example. These are the strongest known permanent magnets and are central to applications in electric motors, wind turbines, and consumer electronics.

One alternative is **ferrite magnets** (iron oxide-based), which are **abundant and inexpensive**, requiring no rare earths at all. However, their **magnetic strength is far lower**. An electric motor based on ferrite magnets would need to be **significantly larger and heavier** to achieve comparable performance—an impractical option for electric vehicles or aircraft propulsion.

Some manufacturers (e.g., **Tesla in earlier models**) opted for **induction motors** (asynchronous motors) that **do not require rare earths**. This helps reduce dependency on **dysprosium and terbium**, but comes at the cost of **lower efficiency** and **increased weight**.

Another alternative is **samarium–cobalt (SmCo) magnets**. While these avoid dysprosium, they still rely on **samarium**, another rare earth element, and on **cobalt**, which is expensive and geopolitically sensitive. SmCo magnets remain stable at temperatures up to 300°C and were historically used in **military and aerospace applications**. However, their **magnetic performance is slightly inferior**, and their cost and material constraints have limited widespread adoption.

Other Sectors: Where Substitution Works—Partially

In **lighting**, for example, the shift from **fluorescent lamps** (which used europium and yttrium-based phosphors) to **LEDs** has significantly reduced rare earth demand. LEDs use different phosphor technologies, often based on **cerium-doped yttrium aluminum garnet (YAG)**, and require **less rare earth material per lumen**.

Catalytic converters could theoretically operate without cerium, using **platinum group metals or other oxides** instead. However, these alternatives are usually **less effective** and **much more expensive**, making them impractical for mass deployment.

In **glass polishing**, cerium oxide is hard to beat. Alternatives like **aluminum oxide or silicon carbide** exist but offer **lower precision and slower polishing rates**, resulting in **higher production costs or quality loss**.

Nickel–metal hydride (NiMH) batteries, which require large amounts of **lanthanum**, have largely been **replaced by lithium-ion batteries** in the automotive sector.

While this reduces demand for rare earths, lithium-ion batteries themselves rely on **other critical materials** such as cobalt, nickel, and lithium—introducing new vulnerabilities.

Thrifting, Design, and Recycling: Making Smarter Use of Rare Earths

Where full substitution is impossible, manufacturers focus on **"thrifting"**—reducing the amount of rare earths used per unit.
For instance, **magnet producers** have lowered **dysprosium content** in modern NdFeB magnets through techniques such as **grain boundary diffusion**, where dysprosium is applied only to the outer layers of magnetic particles, maintaining performance while using less material.

Automotive engineers are redesigning motors and generators to operate at **lower temperatures**, reducing the need for high-temperature stability additives like dysprosium or terbium.

Recycling also offers a path to reducing primary demand. Rare earths can, in theory, be recovered from **end-of-life magnets**, **lighting systems**, and **electronics**. However, rare earth recycling remains **technically complex and economically challenging**, and today accounts for **only a small fraction of total supply**.

Bottom Line: Substitution Helps—but Doesn't Eliminate Dependency

Despite promising developments, rare earths remain largely irreplaceable in many high-tech applications. Their magnetic, optical, and catalytic properties are unique and difficult to replicate.

A case in point: During the 2010 export restrictions, numerous companies experimented with rare-earth-free solutions—hard drive manufacturers turned to ferrite magnets, automakers tried induction motors. Yet once prices normalized, **most reverted to rare earths**, simply because **no other material offers the same level of performance**.

The reality is that substitution can mitigate—but not eliminate—dependency. The most promising path forward is a diversified sourcing strategy, smarter material use, and ongoing innovation in recycling and design. This combination can reduce vulnerability while retaining the full functional advantages of rare earth elements.

10. UKRAINE

Ukraine's Rare Earth Potential – A Sleeping Giant?

Ukraine is rarely mentioned in mainstream reports on rare earth elements (REEs)—neither as a producer nor as a major reserve holder. This is largely due to the fact that **no commercial rare earth mining currently exists** in the country, and although **geological deposits are known**, they remain **undeveloped**.

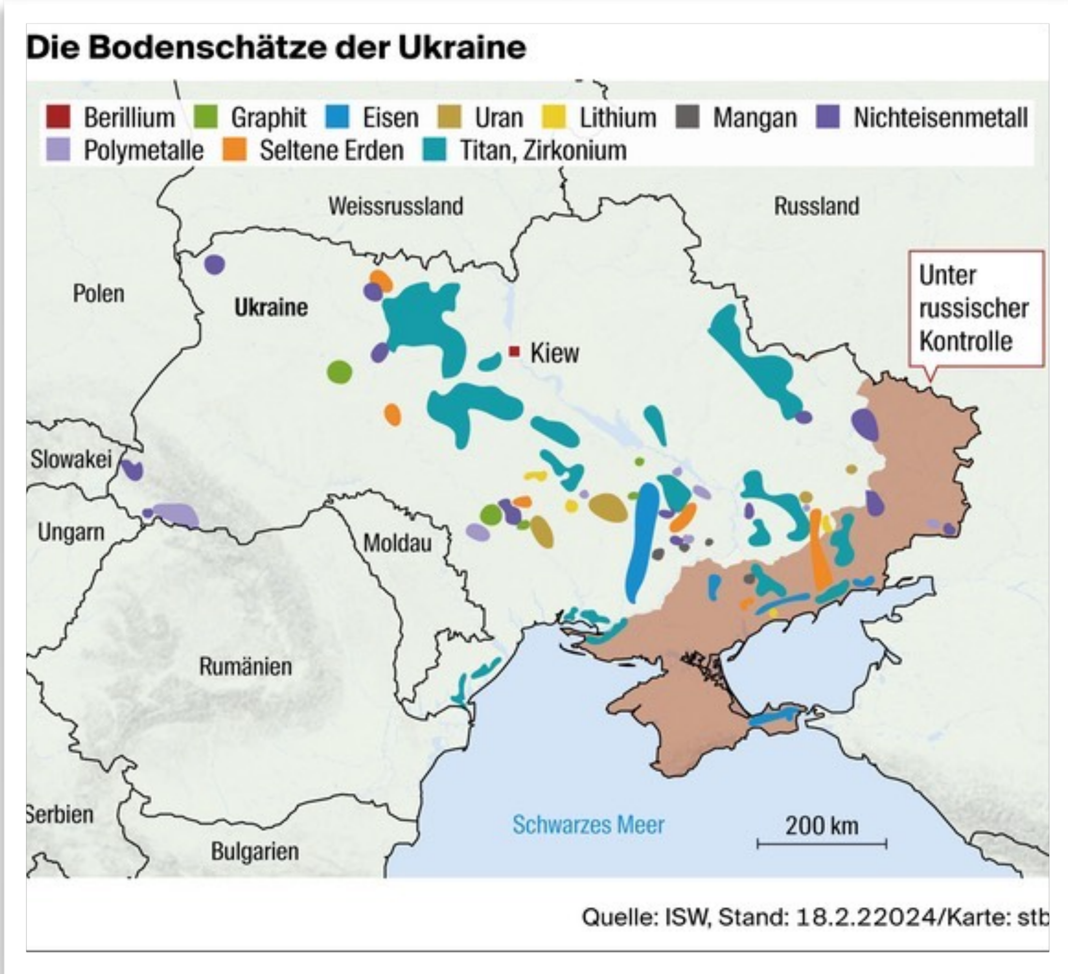
According to the **Ukrainian Ministry of Economy**, the country holds deposits of **22 out of the 34 raw materials** classified as **critical by the European Union**. Among them are rare earth elements such as **lanthanum, cerium, and neodymium**, identified in various Ukrainian ore bodies.

5% of Global Reserves?

Estimates by the United Nations suggest that Ukraine may possess around 5% of the world's rare earth reserves—equivalent to approximately 6 to 7 million metric tons (Mt) of REEs.
For comparison:

- China: ~44 Mt
- Vietnam, Russia, Brazil: ~20 Mt each

If these estimates prove accurate, Ukraine would hold the largest REE reserves in Europe.



Why Does Ukraine Play No Role Today?

There are two main reasons:

1. **Lack of production infrastructure**: Even though deposits—such as those in central Ukraine—are geologically verified, **no mining operations have been launched**.
2. **Complex geology**: Ukrainian REEs are often found in **mixed mineral deposits**, such as **phosphate-rich rock**, **titanium–zirconium sands**, or other mineral complexes.

For example, the **Novopoltavske deposit** in southeastern Ukraine is a large **phosphate–rare earth occurrence**, but it would require an estimated **$300 million USD** to develop—an investment that has not materialized so far.

Barriers to Development

- **Political instability**, including the annexation of Crimea in 2014 and the full-scale war with Russia since 2022, has **frozen many large-scale mining initiatives**.
- **Foreign investors** have been hesitant to enter such a high-risk environment, while **domestic companies lack the capital** and technological capabilities to establish a competitive REE industry.
- Although the EU and Ukraine launched a strategic partnership on raw materials in 2021, Ukraine remains in the resource identification stage, not in active exploitation.

The Ukrainian **Geological Survey** has repeatedly emphasized the country's **significant potential**—six REE deposits have been documented, many of them located in **eastern Ukraine**, where active fighting continues.

As long as the war persists and foreign capital stays away, this potential remains theoretical. Ukraine is not listed in any USGS rare earth production or reserve tables, simply because its data is either unverified, inconsistent, or not economically assessed to global standards.

Looking Ahead: A Post-War Opportunity?

In the **long-term future**, Ukraine could become **an important supplier** of rare earths—especially if **reconstruction funds** are used to develop a REE project as part of **broader industrial support**. Europe, in turn, would benefit from a **more diversified sourcing base**.

The oft-cited estimate of 5% of global reserves is **promising**, but one must remember: Between **proven reserves** and **actual production** lies a long and complex journey:

- Permitting
- Mine development
- Construction of separation and processing facilities
- Environmental controls
- Skilled labor and rare earth-specific know-how

Especially for REEs, the midstream step of separation and refining is technically demanding and not easily built from scratch.

Conclusion: High Potential, Low Short-Term Relevance

Realistically, Ukraine will not become a significant player in the global REE market within the next 5–10 years. For now, it remains a blind spot in international resource reports—not because of a lack of promise, but because of the current geopolitical and industrial realities.

From the standpoint of **short-term supply security**, Ukraine plays **no role at all**.
In the **medium term**, however—assuming peace, investment, and focused development—it may become **one of several contributors** to reducing Western dependency on China.

3. GREENLAND & CANADA - WHY?

🇬🇱 Greenland

Greenland holds significant rare earth element (REE) deposits, most notably at the Kvanefjeld and Tanbreez projects:

- Kvanefjeld: Estimated to contain 6.6 million metric tons (Mt) of rare earth elements
- **Tanbreez**: Holds approximately **5.0 Mt** of REEs

Together, **Greenland's total REE reserves are estimated at around 11.5 Mt**.
However, the development of these resources has been **delayed by environmental concerns and political decisions**, particularly regarding uranium by-products and local opposition to large-scale mining near ecologically sensitive areas.

🇨🇦 Canada

Canada is among the countries with the **largest known reserves of rare earth elements**, with estimates exceeding **15.2 million metric tons**.
Projects such as **Nechalacho** and **Hoidas Lake** are focused on the extraction of REEs—especially the **heavy rare earths** like **dysprosium** and **terbium**.

Canada is also **actively investing** in the expansion of **processing capabilities and recycling technologies**, aiming to build a **complete domestic value chain** for rare earths—from mining and separation to end-use applications.

4. SUMMARY

Rare Earths – The Invisible Foundation of Modern Civilization

Rare earth elements are the **invisible foundation** of our modern world—**small in volume, immense in impact**. They are found in sensors, motors, displays, satellites, lasers, and defense systems. Without them, neither the **green transition** nor **digital transformation** would be possible.
And precisely because of this, they lie at the heart of a **new geopolitical reality**.

China’s dominance in both **mining and processing** has made **Western economies vulnerable**—technologically, economically, and politically. The escalating trade conflict

with the United States, the wave of **export controls**, and Donald Trump's bizarre yet strategically driven overtures toward **Canada, Greenland, and Ukraine** all reveal a central truth:
Control over critical raw materials has become a question of global power.

The world is transitioning to a new resource order—one in which oil and gas no longer dictate the rules, but rather dysprosium-laced magnets, neodymium-based sensors, and cerium-polished fiber optics.
Whoever controls the supply chains for these materials sets the terms.

This report seeks to make this **emerging order visible and understandable**—through facts, analysis, and context. Because only those who recognize the **invisible forces behind visible conflicts** can act with confidence in an era of **resource power and systemic rivalry**.

Christian Rook