MICA
Minerals Intelligence Capacity Analysis

# *DOCSHEET*

# Criticality of mineral raw materials

A review of the criteria that make some mineral raw materials critical. Based (i) on a publication of the National Research Council of the National Academies: 'Minerals, Critical Minerals, and the U.S. Economy (2007), and (ii) the POLINARES project (2010-2012).

## Scope

**What is a critical mineral?**

Based on: Minerals, critical minerals, and the US economy, by the National Research Council of the National Academies (2007 - http://www.nma.org/pdf/101606_nrc_study.pdf, modified). Note that this overview can be profitably completed by the reading of the Critical Metals Handbook (G. Gunn Editor, 2014).

Recognizing that a nonfuel mineral or mineral product can be obtained as either primary or secondary material, what does it mean to say that one of these minerals or mineral products is a "critical" mineral?

In the context of communications regarding minerals, the terms "critical" and "strategic" as mineral or material descriptors have been closely associated, but usually not clearly differentiated. A review of some of these definitions is useful before describing the definition of "critical mineral". See also the dedicated DocSheet '**Strategic, critical, high-tech, rare, and minor metals**'.

DeYoung et al. (2006) noted that historically, "strategic materials" in the United States have generally been associated with material availability in times of war or national emergency; the term "critical material" did not enter the federal lexicon until just prior to World War II when it was introduced in the language for the Strategic and Critical Materials Stock Piling Act of 1939 (Pub. L. 96-41, 1939). The current Strategic and Critical Materials Stockpiling Act (2005 [50 U.S.C. 98 et seq.]) defines strategic and critical materials to be those that are needed to supply the military, industrial, and essential civilian needs of the United States during a national emergency and which are not found or produced in the United States in enough quantities to meet such needs. Specific distinctions between “strategic” and “critical” are not offered in these documents.

The association of the term “strategic mineral” almost exclusively with national security and military needs or requirements during national emergencies is implicit in the synonyms for “strategic” which include planned, tactical, and calculated. “Critical” in general English usage can refer to something that is vital, important, essential, crucial, or significant. **These differences are supported and further refined by definitions in the academic literature that suggest materials for military uses are strategic, while those for which a threat to supply from abroad could involve harm to the nation’s economy are critical (Evans, 1993 in DeYoung et al., 2006)**. This definition builds upon the use of the term “critical materials” in the context of discussion around the establishment of the National Critical Materials Council in the mid 1980s. Critical materials in this context encompassed any material—from metals to alloys to composites—upon which the economic health and national security of the nation resided (Robinson, 1986). A “critical material” thus has broader connotations than a “strategic” material and its definition can be considered to include civilian, industrial, and military applications that could have measured effects on the nation’s economy should supply of a material under evaluation become restricted. **In accordance with these definitions, a “critical” material may or may not be “strategic”, while a “strategic” mineral will always be critical**.

**A material can be regarded as critical only if it performs an essential function for which few or no satisfactory substitutes exist**. **This dimension of criticality is therefore related to the demand for a material that meets very precise specifications required in certain key applications**, but is not simply related to overall demand for all applications. Instead, it reflects the economic, social and other consequences if essential functions cannot be delivered. In addition, **a material can be regarded as critical only if an assessment also indicates high probability that the supply of the material may become restricted, leading either to physical unavailability or significantly higher prices for that material in key applications**. In turn, the probability of a restriction in supply of a critical material is more likely to be assessed as high if the aggregate demand for key applications represents a relatively high proportion of the overall supply of material that meets the required specifications. The report emphasizes also the **distinction between minerals that are *essential* to the economy in certain applications and are yet *not critical*, at least at present, in that the risk of supply restriction is low**.

In its work, the committee found the concept of a “criticality matrix” to be a useful way to characterize the many variables that influence a mineral’s criticality. Determining a mineral’s criticality, then, is a means by which decision makers can help alleviate potential impacts of a mineral’s supply restriction, or avoid a supply restriction entirely through informed decisions.

**What Makes a Mineral Critical?** (see also: http://dels.nas.edu/resources/static-assets/materials-based-on-reports/reports-in-brief/critical_minerals_final.pdf)

The report’s authoring committee developed a “criticality matrix” to aid in assessing a mineral’s degree of criticality (Figure 1). **The matrix is based on the finding that a mineral is critical if it is both important in use (represented on the y-axis of the matrix) and if it is subject to potential supply restrictions (represented on the x-axis of the matrix)**. The methodology provides a framework for federal agencies, decision makers, the private sector, and any user interested in minerals to make assessments about their own “critical” minerals, and upon that basis, to determine what data, information, and research are needed to mitigate potential restrictions in the supply of that mineral for an existing or future use.

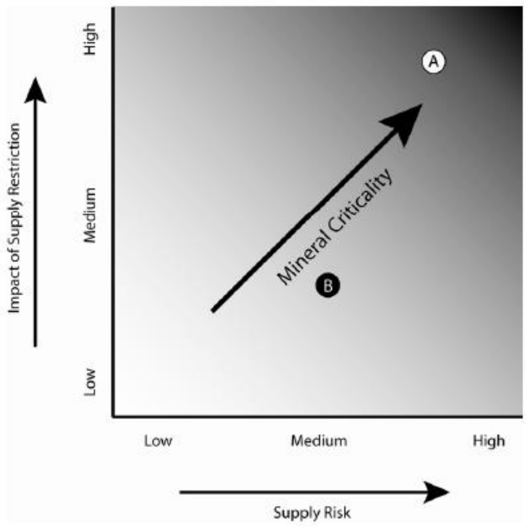


**Figure 1.** The criticality matrix allows evaluation of the "criticality" of a given mineral. A mineral is placed on this figure after assessing the impact of the mineral's supply restriction (importance in use on the y-axis) and the likelihood of a supply restriction for that mineral (x-axis). The degree of criticality increases from the lowerleft to the upper-right corner of the figure: in other words, mineral A is more critical than mineral B.

***Factors that affect minerals importance in use:***

Minerals have varying levels of "importance" as a result of the demand for that mineral from different sectors of the U.S. economy. "Importance in use" carries with it the concept that some minerals will be more fundamental for specific uses than other minerals, depending on the mineral's chemical and physical properties. **The greater the difficulty, expense, or time to find a suitable substitute for a given mineral, the greater will be the impact of a restriction in the mineral's supply** (see also the dedicated DocSheet '**Substitution: the CRM-InnoNet vision**'). For example, platinum group metals and rare earth elements are fundamental to the construction and function of automobile catalytic converters.

***Factors affecting availability of minerals:***

**Over the long term (more than about ten years), availability is a function of five factors**: **geologic** (does the mineral resource exist); **technical** (can we extract and process it); **environmental and social** (can we produce it in environmentally and socially accepted ways); **political** (how do governments influence availability through their policies and actions); and **economic** (can we produce it at a cost users are willing and able to pay).

Many existing and emerging technologies require minerals that are not available in the United States, but a high degree of import dependence for certain minerals is not, in itself, a cause for concern. However, import dependence can expose a range of U.S. industries to political, economic and other risks that vary according to the particular situation. Informed planning to maintain and enhance domestic economic growth requires knowledge of potential restrictions in the supply of minerals, and also the development of strategies to mitigate the effects of those restrictions.

In the short- and medium-term, significant restrictions to supply may occur, leading either to physical unavailability of a mineral or more likely, to higher prices. Risks include the following:

▸ A significant and unexpected increase in demand, especially if production is already at or close to capacity.
▸ Relatively thin (or small) markets, which may make it difficult to quickly increase production in response to demand.
▸ Production concentrated in a small number of mines, a small number of companies, or a small number of producing countries.
▸ Minerals whose supply consists significantly of byproduct production, which may be fragile or risky because availability is determined largely by availability of the main product (for example, gallium as a byproduct of bauxite mining).
▸ Markets for which there is no significant recovery of material from old scrap, which may be more prone to supply risk than otherwise.

**SUMMARY OF THE ABOVE PRESENTED CRITERIA**

• **All minerals and mineral products could be or could become critical to some degree, depending on their importance and availability**.
• **From the USA perspective, a critical mineral is one that is both essential in use *and* subject to the risk of supply restriction**.
• **The criticality of a specific mineral can and likely will change as production technologies evolve and new products are developed.**
• **The greater the difficulty, expense, or time it takes for material substitution to occur, the more critical a mineral is to a specific application or product—or analogously, the greater is the impact of a mineral supply restriction.**
• **The criticality matrix methodology is a useful conceptual framework for evaluating a mineral's criticality in a balanced manner in a variety of circumstances that will be useful for decision makers in the public and private sectors**. A more nuanced and quantitative version of the matrix could be established and used as part of the federal program for minerals data collection, analysis, and dissemination.
• In employing the methodology, **it is important to distinguish among three time or adjustment periods**: **the short term**, **the medium term**, **and the long term**.
• **In the short and medium term, significant restrictions to mineral supply may be due to: 1) significant increase in demand; 2) thin markets; 3) concentration of production; 4) production predominantly as a byproduct; 5) lack of available old scrap for recycling or of the infrastructure required for recycling.**
• **Over the longer term, availability of minerals and mineral products is largely a function of investment and the various factors that influence the level of investment and its geographic allocation and success. Long-term availability of minerals and mineral products also requires continued investment in minerals education and research.**
• As an indicator of vulnerable supply, **import dependence by itself is not a useful indicator of supply risk**. Rather, for imports to be vulnerable to supply restriction, some other factor must be present that makes imports vulnerable to disruption—for example, supply is concentrated in one or a small number of exporting nations with high political risk or in a nation with such significant growth in internal demand that exported minerals may be redirected toward internal, domestic use.
• Of the eleven minerals or mineral families the committee examined, **those that exhibit the highest degree of criticality at present are: PGMs, REs, indium, manganese, and niobium**. [note: study published in 2007 for the USA]
• **Decision makers in both the public and private sectors need continuous, unbiased and thorough minerals information provided through a federally funded system of information collection and dissemination**. [note: study published in 2007 for the USA]
• **The effectiveness of a government agency or program is dependent on the agency's or program's autonomy, its level of resources, and its authority to enforce data collection. Federal information**

**gathering for minerals at present does not have sufficient authority and autonomy to appropriately carry out its data collection, dissemination, and analysis. In particular, the committee concludes that USGS Minerals Information Team activities are less robust than they might be, in part because it does not have status or resources to function as a "principal" statistical agency.** [note: study published in 2007 for the USA]
• **More complete information needs to be collected, and more research needs to be conducted, on the full minerals life cycle**.

**'Rethinking critical raw materials' – The POLINARES Project recommendations for the EU** (http://www.polinares.eu/docs/polinares_final_results.pdf)

Polinares (Policy for Natural Resources) was a €2.7 million project funded by the European Commission and which examined the global challenges faced with respect to access to oil, gas and mineral resources over the next 20 years and proposes solutions for the various policy actors, including the EU

Existing published studies on raw materials attempt to identify minerals which are "critical" to the EU, by applying in combination such measures as: country risk; country concentration of the resource; import dependency; and economic importance to the EU. The POLINARES evaluation of these indicators provides an indication of potential critical minerals. However, the indicators have a number of deficiencies, for example:

- They lack predictive power beyond the short term;
- They fail to distinguish between short-term and long-term problems;
- They fail to take into account solutions that eliminate the problem over the long-term, such as technological innovation and material substitutability;
- They do not take sufficient account of the diversity and particular characteristics of the resource markets that are analysed.
- They tend to implicitly overstate the economic impact of a possible supply disruption of the "critical" mineral;

As a consequence POLINARES proposed that future assessments of criticality focus on the major likely sources of supply risk, rather than on specific minerals, namely:

- Accidental supply disruptions and price hikes;
- Intentional supply disruptions by the use of export restrictions or pricing as a political tool;
- Unequal market conditions causing an uneven economic playing field;
- Governance issues related to the resource sector.

Such a framework would form the basis for a much more comprehensive evaluation of raw material criticality, as it would be based on a problem-oriented approach which should support long-term policy making more effectively than a list of critical minerals.

Through POLINARES, Buijs et al. (2012), provided an informative review of the criteria used by several countries for defining critical minerals and the critical minerals themselves (Table 1).

| **Study** | **Criteria** | **Critical minerals** |
|---|---|---|
| | ■ US consumption (value) | |

| | | |
|---|---|---|
| | ■ Substitutability<br>■ Emerging uses<br>■ US import dependence<br>■ Ratio of world reserves to production<br>■ Ratio of world reserve base to production<br>■ World by-product production compared with total primary production<br>■ US secondary production from old scrap compared with consumption | earths |
| REKTN (2008) (UK) | ■ Global consumption levels<br>■ Lack of substitutability<br>■ Global warming potential<br>■ Total material/environmental requirement<br>■ Physical scarcity<br>■ Monopoly supply<br>■ Political instability<br>■ Climate change vulnerability | |
| | ■ Basic availability<br>■ Competing technology demand<br>■ Political, regulatory and social factors<br>■ Co-dependence on other markets<br>■ Producer diversity<br>■ Demand for clean energy<br>■ Substitutability | |
| | ■ Concentration of supply<br>■ Governance rating of producing countries (alternatively environmental performance)<br>■ Substitutability<br>■ Recycling rate<br>■ Value added of end user sectors | |
| | ■ Share of Germany in world consumption<br>■ Change in the share of Germany in world consumption<br>■ Change in imports<br>■ Sensitivity of the relevant value chains in Germany<br>■ Demand from emerging technologies<br>■ Substitutability<br>■ Governance of producing countries<br>■ Governance of countries selling to Germany<br>■ Country concentration of reserves<br>■ Company concentration of production<br>■ Ratio of reserves to production<br>■ Share of by-product production in world production<br>■ Recyclability | |

Table 1. Selection of recent studies identifying critical non-energy raw materials for different countries and regions (Buijs et al., 2012).

| | |
|---|---|
| Contexts of use, application fields | -> contexts (e.g., environmental, economic, social assessment)<br>-> which types of stakeholder questions are concerned?<br>-> link to published studies that implement the method |

▶ Not applicable

| | |
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| Input parameters | -> which parameters are needed to run the method |

▶ Not applicable

| | |
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| Type(s) of related input data or knowledge needed and their possible source(s) | -> which types of data are needed to run the method, from which sources could they come…<br>-> could be qualitative data or quantitative data, and also tacit knowledge, hybrid, etc. |

▶ Not applicable

| | |
|---|---|
| Model used (if any, geological mathematical, heuristic…) | -> e.g., geological model for mapping<br>-> e.g., mathematical model such as mass balancing, matrix inversion, can be stepwise such as agent -based models, dynamic including time or quasidynamic specifying time series…<br>-> can also be a scenario |

▶ Not applicable

| | |
|---|---|
| System and/or parameters considered | -> **the system can be described by its boundaries**. These can refer to a geographic location, like a country, or a city, the time period involved, products, materials, processes etc. involved, like flows and stocks of copper, or the cradle-to-grave chain of a cell phone, or the car fleet, or the construction sector, or the whole economy…<br>-> **parameters** could possibly refer to geographic co-ordinates, scale, commodities considered, genesis of ore deposits and others… |

▶ Not applicable

| | |
|---|---|
| Time / Space / Resolution /Accuracy / Plausibility… | -> to which spatio-temporal domain it applies, with which resolution and/or accuracy (e.g., near future, EU 28, 1 year, country/regional/local level…)<br>-> for foresight methods can also be plausibility, legitimacy and credibility… |

▶ Not applicable

| | |
|---|---|
| Indicators / Outputs / Units | -> this refers to what the method is actually meant for. Units are an important part but that is most of the time not sufficient to express the meaning. For example, **the indicators used in LCA express the cradle-to-grave environmental impacts of a product or service**. This can be expressed in kg $CO_2$-equivalent. But also in €. Or in millipoints. Or in $m^2$year land use.<br>-> for foresight methods the outputs are products or processes |

▶ Not applicable

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| Treatment of uncertainty, verification, validation | -> evaluation of the uncertainty related to this method, how it can be calculated/estimated |

▶ Not applicable

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| Main publications / references | -> e.g. , ILCD handbook on LCA, standards (e.g. , ISO)<br>-> can include reference to websites/pages<br>-> references to be entered with their DOI |

Buijs B., Sievers H., Tercero Espinoza L.A. (2012). Limits to the critical raw materials approach, Proceedings of the ICE - Waste and Resources Management, 165 (4), p. 201-208. https://doi.org/10.1680/warm.12.00010

DeYoung J.H., McCartan L., Gambogi J. (2006). What's been (and what will be) strategic – My metal or your paint? In Reid, J.C. (ed.), Proceedings of the 42nd Forum on the Geology of Industrial Minerals: Information Circular 34, North Carolina Geological Survey.

Erdmann L., Behrendt S., Feil M. (2011). Kritische Rohstoffe für Deutschland. „Identifikation aus Sicht deutscher Unternehmen wirtschaftlich bedeutsamer mineralischer Rohstoffe, deren Versorgungslage sich mittel- bis langfristig als kritisch erweisen könnte“. Im Auftrag der KfW Bankengruppe. https://www.kfw.de/Download-Center/Konzernthemen/Research/PDF-Dokumente-Sonderpublikationen/Kritische-Rohstoffe-KF.pdf

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http://www.nma.org/pdf/101606_nrc_study.pdf
International Standard Book Number-13: 978-0-309-11286-4
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http://dels.nas.edu/resources/static-assets/materials-based-on-reports/reports-in-brief/critical_minerals_final.pdf

POLINARES – EU policicy on mineral resources – (http://www.polinares.eu/)
Summary of project results published (http://www.polinares.eu/news/preview.php?id=44)
http://www.polinares.eu/docs/polinares_final_results.pdf

REKTN (2008). Material Security: ensuring resource availability for the UK economy.
http://www.oakdenehollins.com/pdf/material_security.pdf

Robinson A.L. (1986). Congress critical of foot-dragging on critical materials. Sciences 234, no. 4772, p. 20-21. *JSTOR*, www.jstor.org/stable/1697368

| | |
|---|---|
| Related methods | -> List of comparable methods, their particularities…<br>-> link to one or several other existing fact sheet(s) |

Links with the following FactSheet/DocSheet:

- DocSheet ‘**Strategic, critical, high-tech, rare, and minor metals**’
- DocSheet ‘**Substitution: the CRM-InnoNet vision**’

| | |
|---|---|
| Some examples of operational tools (CAUTION, this list is not | -> e.g., software… Only give a listing and a reference (publication, website/page…)<br>-> **should be provided only if ALL main actors are properly cited** |

| exhaustive) | |
|---|---|

▶ Not applicable

| Key relevant contacts | -> list of relevant **types** of organisations that could provide further expertise and help with the methods described above. |
|---|---|

- POLINARES project: http://www.polinares.eu/contact_us.html
- Fraunhofer ISI: http://www.isi.fraunhofer.de/isi-de/
- BGR: http://www.bgr.bund.de/EN/Home/homepage_node_en.html
- BRGM/DGR/OEG: http://www.brgm.fr/ ; http://www.brgm.eu/
- GSI: http://www.gsi.ie/

| Glossary of acronyms /abbreviations used | -> Definition |
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