THE NATIONAL ACADEMIES
REPORT IN BRIEF

Minerals, Critical Minerals, and the U.S. Economy

If the supply of any of the minerals used in everyday products and services was curtailed, consumers and sectors of the U.S. economy could be significantly affected. Although baseline information on minerals is collected at the federal level, there is currently no established methodology to identify critical minerals—those that are both important in use and for which there is a potential for supply restriction. This report suggests a framework for identifying critical minerals and the data and research needed to support it.

Minerals are part of virtually every product we use. Their unique properties contribute to provision of food, shelter, infrastructure, transportation, communications, health care, and defense. Minerals used in common applications include iron to produce steel, copper used in electrical wiring and plumbing, and titanium used for the structural frames of airplanes and in paint pigments. Every year over 25,000 pounds (11.3 metric tons) of new minerals must be provided for every person in the United States to make the items that we use every day, and a growing number of these minerals are imported.

The portfolio of minerals needed for manufacturing is dynamic. The Information Age is creating demand for an ever-wider range of metallic and nonmetallic minerals to perform essential functions in cellular telephones (e.g., tantalum), liquid crystal displays (e.g., indium), computer chips (a broad mineral suite), and photovoltaic cells (e.g., silicon, gallium, cadmium, selenium, tellurium, and indium). Whereas today's cars require about 50 pounds of copper to create electrical wiring systems, new hybrid cars will require even more copper—about 75 pounds, by some estimates.

There are a number of reasons for potential supply restrictions. Natural ores can be exhausted or become too difficult to extract economically or in an environmentally acceptable way. For some minerals, reliance on supplies from a limited number of mines, mining companies or nations can carry added potential for restriction. Increases in mineral demand with new technology development can also alter mineral prices. For example, in response to an increase in demand for indium, used in the manufacture of flat screens, the price of indium rose from about $100 per kilogram to $980 per kilogram between 2003 and 2006.

Given the importance of minerals and a growing reliance on imported minerals, concerns have been raised that the impacts of potential restrictions for mineral supplies have not been adequately articulated, and that federal responsibilities to acquire and disseminate information and conduct research on "critical" minerals are not well defined. The central question is, will the necessary mineral resources be available in time and at acceptable costs to meet burgeoning demand for current and emerging products and technologies?

This report investigates and highlights the importance of minerals in modern U.S. society, which minerals might be termed "critical" and why, the extent to which the availability of these minerals is subject to restriction, and the data, information, and research needed to aid decision makers in taking steps to avoid restrictions in

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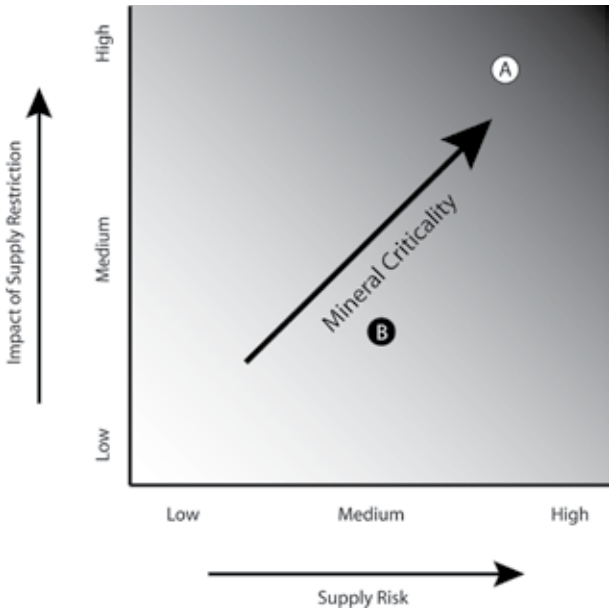

Figure 1. The criticality matrix as established in this report allows evaluation of the "criticality" of a given mineral. A mineral is placed on this figure after assessing the impact of the mineral's supply restriction (importance in use on the y-axis) and the likelihood of a supply restriction for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

mineral supply. The audience for the study includes not only federal agencies, industry, and research organizations, but also the general public and decision makers.

What Makes a Mineral Critical?

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.

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 (Figure 2). 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.

For example, platinum group metals and rare earth elements are fundamental to the construction and function of automobile catalytic converters. At present,

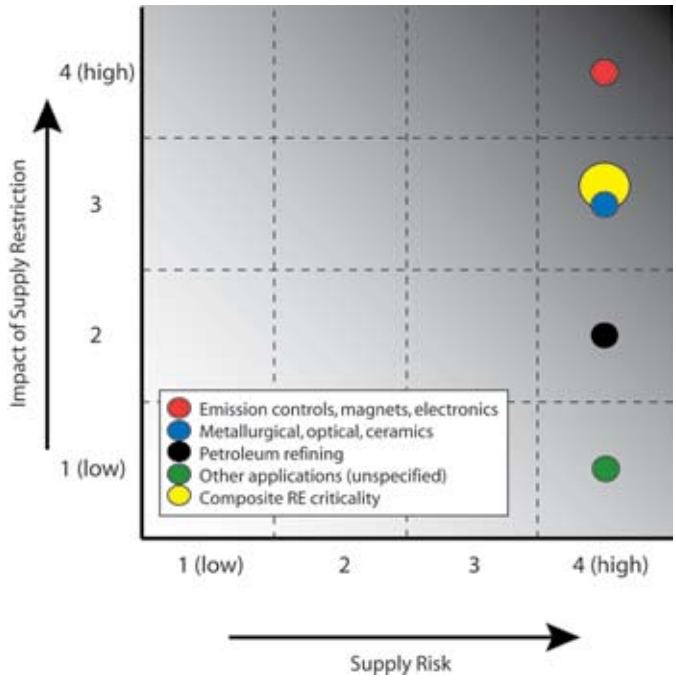

Figure 2. Applying the criticality matrix. The matrix shows criticality of the group of minerals known as rare earths. The impact of supply restriction (on the y-axis) is evaluated by examining the annual quantity of rare earths used in each of four rare earth application groups (red, blue, black, and green circles), and the difficulty in finding substitutes for rare earths in those applications. Because no ready substitutes exist for rare earths in emission controls, magnets and electronics, and these applications demand the greatest quantities of rare earths annually, it is assigned a y-axis value of 4. The yellow dot represents the weighted score for all applications of the impact of supply restriction. The high supply risk (a score of 4 on the x-axis) is due primarily to the fact that the U.S. is 100% dependent on foreign suppliers, most of which (76%) is concentrated in a single country (China).

no viable substitutes exist for these minerals in this application, resulting essentially in a 'no-build' situation for catalytic converters should the supply of those minerals be restricted. These minerals' importance is high in this application.

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 already is occurring at 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.

Using the Matrix

The report applies the criticality matrix to 11 minerals/mineral groups: copper, gallium, indium, lithium, manganese, niobium, platinum group metals, rare earth elements, tantalum, titanium, and vanadium (Figure 3). This list should NOT be construed as a comprehensive list of potentially "critical" minerals; but rather those determined by the committee to demonstrate the range of factors over which the matrix methodology could be tested, and which could be reviewed within the time constraints of the study.

Of the 11 minerals that the report examines, platinum group metals, rare earths, indium, manganese, and niobium, were determined to be most "critical". Their uses and applications, the difficulty in finding appropriate mineral substitutes for these applications, and the risk to their supply for any one of a number of reasons were high enough to place these minerals in or near the critical "zone" of the criticality matrix. While important applications exist for the other minerals examined in the report (copper, gallium, lithium, tantalum, tita-

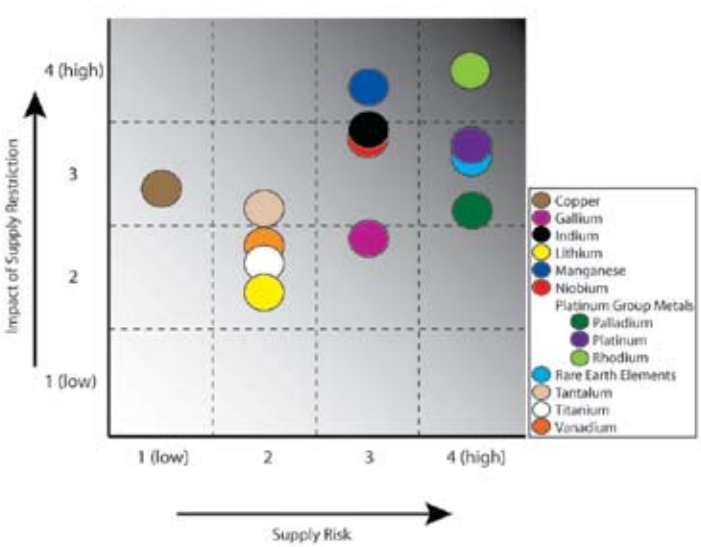

Figure 3. Application of the matrix to 11 minerals. The criticality of 11 minerals/mineral groups was assessed by the report's authoring committee using the criticality matrix. The circles for each mineral represent the composite score on a scale of 1 to 4 on each axis of the impact of a supply restriction and the supply risk. Of those examined, platinum group metals, rare earths, indium, manganese, and niobium were found to be most critical (upper right corner of matrix).

nium, and vanadium), they were identified as less critical, either because there were ready substitutes, or because supplies were not potentially prone to restriction at present. The report did not speculate on the potential for new, or frontier, applications to drive new demand for these or other minerals in the future.

Minerals Information and Research

The report concurs with the consensus of private, academic, and federal professionals that the U.S. Geological Survey (USGS) Minerals Information Team is the most comprehensive and responsive source of minerals information domestically and internationally, but that the quantity and depth of its data and analysis have fallen in recent years, due in part to reduced or static budgets and to resultant reductions in staff and data coverage. As presently configured, federal information gathering for minerals does not have sufficient authority, autonomy, and resources to appropriately carry out its data collection, dissemination, and analysis.

The USGS could add information critical minerals to the types of data it is now collecting. Unfortunately, there is a paucity of information on critical minerals due in part to an inappropriately low level of support for data collection related to mineral resource availability and resource technology. The report identifies several research areas that are important if critical minerals are to be reliably identified, if their sources are to be better quantified, and if extraction and processing technology is to be substantially enhanced.

Well-educated resource professionals are essential for fostering the innovation necessary to assure resource availability at acceptable costs and with minimal environmental damage. Unfortunately, the infrastructure for adequate training of professionals to service the mineral sector has declined substantially over the past few decades in almost all industrialized countries, and the current pipeline of training in the United States does not have enough students to fill the present or anticipated future needs of the country.

RECOMMENDATIONS

Recognizing the dynamic nature of mineral supply and demand and of criticality, and in light of the conclusions above, the committee makes the following recommendations:

1. The federal government should enhance the types of data and information it collects, disseminates, and analyzes on minerals and mineral products, especially as these data and information relate to minerals and mineral products that are or may become critical.

2. The federal government should continue to carry out the necessary function of collecting, disseminating, and analyzing minerals data and information. The USGS Minerals Information Team (MIT), or whatever federal unit might later be assigned these responsibilities, should have greater authority and autonomy than the USGS MIT does at present. It also should have sufficient resources to carry out its mandate, which would be broader than the MIT's current mandate if our recommendations are adopted.

3. Federal agencies, including the National Science Foundation, the Department of the Interior (including the USGS), the Department of Defense, Department of Energy, and the Department of Commerce should develop and fund activities, including basic science and policy research, to encourage innovation in the nation in the critical minerals and materials area and to enhance understanding of global mineral availability and use.

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This report brief was prepared by the National Research Council based on the report *Minerals, Critical Minerals, and the U.S. Economy.* For more information, contact the Board on Earth Science and Resources at (202) 334-1289 or visit http://nationalacademies.org/besr. Copies of *Minerals, Critical Minerals, and the U.S. Economy* are available from the National Academies Press, 500 Fifth Street, NW, Washington, D.C. 20001; (800) 624-6242; www.nap.edu.