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Raw materials engineering: challenges, technologies and strategies for sustainable resource management

1. Introduction

Mineral raw materials constitute the basis for the development of nearly every branch of the manufacturing industry, while the availability of domestic mineral resources is a key factor ensuring the stable and secure development of the national economy. The demand for raw materials continues to grow (United Nations Environment Programme & International Resource Panel, 2024), which is partly driven by ongoing global industrial development and advances in emerging technologies and innovative materials. Raw materials can be classified according to various criteria, including their properties and characteristics, intended applications, and extraction and production technologies. It should be noted, however, that a given raw material may fall into more than one category and, depending on the classification perspective adopted, may or may not satisfy the criteria for inclusion in a particular group. For example, copper may be regarded as a strategic raw material in one country but not in another. Nevertheless, the following major categories of mineral raw materials can generally be distinguished:

- energy raw materials, whose primary application is direct or indirect conversion into energy;
- critical raw materials (CRMs), which are characterized by the highest economic importance – particularly in the context of advanced technologies and the energy and digital transitions – while simultaneously being subject to a high risk of supply chain disruptions (Valero et al., 2018). This group includes, among others, rare earth elements (REEs), lithium, cobalt, graphite, and magnesium. Owing to the rapidly increasing demand from the electronics, energy storage, automotive (e.g., electric vehicles), and renewable energy sectors, their secure and stable supply has become a key determinant of the geopolitical and technological security of individual countries;
- metallic mineral raw materials (metal ores), from which metals are produced through a series of processing operations, including mineral processing, beneficiation, and metallurgical treatment. Within this category, a further distinction is often made between iron ores and non-ferrous and precious metal ores;

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- industrial minerals and construction materials, which comprise a broad range of mineral resources used in the production of construction and road aggregates (e.g., sand, gravel, granite, basalt, syenite, porphyry, melaphyre, limestone, and dolomite), mineral binders such as cement, lime, and gypsum binders (derived from limestone, marl, gypsum, anhydrite, and chalk), dimension and building stone (granite, sandstone, marble, syenite, and basalt), structural and fine ceramics (clays, kaolins, and clay shales), glass (quartz sand and quartzitic sandstone), insulation materials such as mineral wool (produced from basalt, gabbro, and dolomite), agricultural mineral fertilizers (limestone, dolomite, and lacustrine chalk), mineral powders and industrial fillers (limestone, dolomite, and chalk), as well as mineral feed additives for livestock (limestone, chalk, dolomite, and others);
- chemical raw materials, primarily rock salt, potash salts, and sulfur, which constitute the basis of the domestic chemical, fertilizer, and pharmaceutical industries and are also used for underground hydrocarbon storage.

2. Industrial and economic importance of raw materials

Energy raw materials are characterized by an enormous global production volume, exceeding 16 billion tons in 2023 (Reichl & Schatz, 2025). Throughout the history of civilization and technological progress, countries endowed with abundant domestic energy resources have consistently played a pivotal role in the global economy and geopolitics. Energy raw materials are widely regarded as strategic resources for several reasons, including the following:

- They enable the production of energy, which is subsequently used in industrial processes and by households. Energy is therefore an essential input to producing consumer and industrial goods, contributing to economic growth and increasing national income.
- The distribution of energy raw materials within the Earth's crust is highly uneven. Together with critical raw materials, they represent some of the most geographically concentrated mineral resources. As a result, only a limited number of countries possess sufficient reserves to generate substantial revenues from their extraction and export.
- Access to low-cost energy sources facilitates technological advancement and economic development by reducing the costs associated with industrial production, innovation, and infrastructure development.

Technological progress in the energy sector, including the development of more efficient energy generation technologies and the increasing role of unconventional, particularly renewable, energy sources, has improved access to affordable electricity, thereby enhancing the development potential of national economies. In parallel, technological advancement – especially the implementation of more technologically advanced and economically efficient production processes – has led to increased consumption of mineral raw materials. Consequently, although technological progress has made manufacturing activities more efficient and relatively less costly, these benefits have been achieved at the expense of growing demand for raw materials.

The development of the energy sector, particularly advanced batteries, energy storage systems, and accumulators, as well as the electronics industry (requiring semiconductors and specialized materials), the defense sector (including sensors and defense systems), navigation technologies, analytical instrumentation, and other high-tech manufacturing industries, is not only highly energy-intensive but also critically dependent on the availability of a wide range of critical raw materials. Alongside energy raw materials, critical raw materials play a fundamental role in global economic development and technological innovation. This is reflected, among other factors, in the growing strategic interest in these resources among the world's leading mining countries and in the steadily increasing demand driven by the expansion of industries based on advanced technologies and innovative materials.

Metal ores constitute the foundation of the global heavy and processing industries, and their historical importance for technological development is reflected in the names of entire periods of human civilization. While energy raw materials drive economic activity, metals obtained from ores form the physical foundation and industrial infrastructure of modern economies. The production of useful end products from these resources requires a series of complex processes, including mineral processing, beneficiation, and metallurgical treatment. Due to their economic significance and final applications, metal ores are generally divided into three main subgroups, each of which supports the development of different industrial sectors:

- iron ores, from which steel and cast iron are produced. They represent an indispensable foundation for the machinery, shipbuilding, automotive, and construction industries (load-bearing structures);
- basic non-ferrous metal ores (including copper, zinc, lead, and bauxite). These resources are essential for power infrastructure, telecommunications, the global energy transition, and the electrification of transport;
- precious metal ores (gold, silver, platinum, and palladium). In addition to their traditional monetary and jewelry applications, they currently represent critical components of advanced electronics, the automotive industry (catalytic converters), medicine, and the rapidly developing space industry (including thermal protection systems and radiation-resistant coatings).

Growing demand for metals, combined with their uneven global distribution, means that access to these resources determines the long-term independence and industrial competitiveness of individual countries.

Although often less highlighted in geopolitical discussions than energy, critical, or metallic raw materials, rock raw materials represent by far the largest group of mineral resources exploited worldwide in terms of production volume. Their global production reached approximately 50 billion tons in 2024 (United Nations Environment Programme & International Resource Panel, 2024). Considering the ongoing urbanization processes and the expansion of transport infrastructure, it is evident that these resources constitute an indispensable foundation for the functioning and development of every modern economy. Their strategic importance results from the fact that they provide the primary material base for civil engineering, construction, and agriculture. Through processes such as crushing, grinding, and thermal treatment, rock raw materials are transformed into a wide range of essential products, including primarily:

- construction and road aggregates (including those derived from sands, gravels, granites, and basalts), which are essential for concrete production and the construction of structural layers in road infrastructure;
- mineral binders, insulation materials and raw materials for the glass and ceramic industry;
- agricultural products, including mineral fertilizers (limestone and dolomite) and animal feed additives (feed-grade chalk and zeolites).

Rock raw materials are characterized by a low unit value combined with very high mass, meaning that their economic competitiveness is largely determined by logistics and transportation costs. Therefore, the availability of a local and domestic resource base is a prerequisite for optimizing the costs of infrastructure investments and supporting economic growth (United Nations Environment Programme & International Resource Panel, 2024).

3. Aims and scope of the "Journal of Raw Materials Engineering"

The raw materials sector provides the essential inputs to produce most industrial and consumer goods. Managing the entire raw materials value chain requires an interdisciplinary approach that integrates technological, economic, environmental, and policy perspectives (Kesler & Simon, 2015). Therefore, raw materials engineering represents a field at the intersection of these interconnected domains.

Raw material extraction technologies are highly complex. They span the entire value chain: from extracting the run-of-mine from the deposit, through mineral processing (the separation of valuable minerals into elements or compounds such as sulfides and oxides), to the metallurgical stage of recovery of pure elements. Ensuring operational safety requires rigorous mine climate control, comprehensive mining operation plans, safety documents, and advanced technical documentation tailored to specific mining methods.

From an economic perspective, extraction costs must be accurately assessed through a technical evaluation of appropriate mining systems for specific resource types. This involves key economic indicators and capital budgeting metrics, including unit extraction costs, capital expenditure (CAPEX), net present value (NPV), discounted payback period (DPP), internal rate of return (IRR), break-even point (BEP), liquidity ratios, and the cost of capital.

The extraction and processing of mineral resources inevitably cause environmental footprints and social friction. Mining operations permanently alter landscapes through excavations and waste heaps, while disrupting hydrogeological systems (e.g., cones of depression, water pollution risks). Furthermore, extraction and processing are direct sources of dust and gas emissions. For local communities, key nuisances include noise, ground vibrations (e.g., from blasting operations), and heavy traffic loading local road infrastructures. Addressing these challenges requires strict adherence to sustainable development principles. Modern mining must deploy low-emission technologies, adopt circular economy models (industrial waste utilization), and execute comprehensive land reclamation to restore ecological balance or repurpose post-mining sites.

The "Journal of Raw Materials Engineering" (JRME) addresses these critical dimensions by publishing high-quality, peer-reviewed scientific articles. The journal provides a platform for papers focusing on issues related to resource management at both local and global scales. We welcome innovative research results and novel technological solutions that drive efficiency and sustainable development across the raw materials industry. The profile of the journal is interdisciplinary, bridging the gap between engineering sciences, applied economic analysis, and environmental policy. The journal publishes original research papers, comprehensive reviews, and impactful case studies that link mining engineering, mineral processing, waste upcycling, resource economics, and green extraction technologies. Special emphasis is placed on submissions that demonstrate a direct pathway from laboratory-scale innovations to industrial-scale feasibility. The journal welcomes contributions addressing, but not limited to:

- mining technologies and automation;
- mineral processing and beneficiation;
- critical raw materials supply chains;
- recycling and circular economy;
- environmental impacts of resource utilization;
- economic and geopolitical aspects of raw materials management.

In the era of accelerating energy transitions and shifting geopolitical alliances, the significance of raw materials engineering has never been more essential. By publishing cutting-edge advancements and fostering international scientific collaboration, JRME aims to contribute to the development of strategies that will secure, optimize, and reduce the carbon intensity of global raw materials supply chains (Valero et al., 2018).

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