Environmental Issues Associated with Expanding Rare and Specialty Metal Resources for Green Technologies

Metals for Energy & the Environment

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Environmental Issues

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  - Science Supply & Demand

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Environmental Issues: Introduction

- Growing demand for critical materials
  - "Many new and emerging clean energy technologies, such as the components of wind turbines and electric vehicles, depend on materials with unique properties"
  - "The availability of a number of these materials is at risk due to their location, vulnerability to supply disruptions and lack of suitable substitutes"
  - "Extraction and processing should be done in an **environmentally** sound manner"
Environmental Issues: Introduction

- **Develop new projects to extract resources**
  - Permitting process is long and difficult
  - Mining generates hazardous wastes
    - Radioactive wastes
    - Concentrated metals:
      - Tailings
      - Waste Effluents
    - Other persistent pollutants

- **Recycle metal scraps/wastes**
  - Methods still developing
  - Costs often outweigh benefits
  - Chemical processing may also generate wastes

- **Develop substitutes**
  - May not eliminate need for some metals
  - Chemical substitutes may be more hazardous than metals themselves
Environmental Issues: Material Supply & Demand

**Materials Supply & Demand versus Science Supply & Demand**

- “Key challenges to the development and deployment of offshore wind technology include the relatively high cost of energy, technical challenges surrounding installation and grid interconnection, and permitting challenges related to the lack of site data and lack of experience with permitting processes for projects in both federal and state waters.”

- “Since no wind turbines are installed in U.S. waters, there is a shortage of critical data on the environmental and sitting effects of turbines and on the installation, operations, and maintenance of these turbines. This lack of data drives up the costs of financing offshore wind projects to the point where financing charges account for roughly half of the cost of offshore wind energy.”
Environmental Issues: Science Supply & Demand

Materials Supply & Demand versus Science Supply & Demand

Number of Toxicity Studies in PubMed Database

- Cerium
- Gallium
- Indium
- Lanthanum
- Neodymium
- Tellurium
- Cadmium
- Copper
- Lead

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Environmental Issues: Science Supply & Demand

**Materials** Supply & Demand *versus* **Science** Supply & Demand

- Environmental regulations require scientific information
  - REACH (European Union)
  - Domestic Substances List (Canada)
  - TSCA (United States)
  - Clean Water Act (United States)
  - Green Chemistry Initiatives (United States)
  - E-Waste/Electronics Recycling (US/EU)
# Environmental Issues

<table>
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<tr>
<th>Process</th>
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| Mining             | Environmental Permitting Process  
*Human and environmental impacts*  
Hazardous waste management/disposal  
*Tailings (Rare, specialty, and base metals)*  
*Effluents (Acids, chemicals)*  
Radioactive waste management/disposal |
| Refining/Processing | Occupational exposure (Exposure standards/criteria)  
Waste management (Disposal/discharge standards/criteria)  
Scrap metal recycling/disposal |
| Commerce/Trade      | Environmental Regulations (REACH, TSCA, etc..)  
Material Safety Data Sheets (MSDS)  
*Requires detailed hazard/toxicity information with increasing complexity with increasing tonnage* |
| Product Safety      | Evaluate products to ensure minimal exposure to metals/chemicals  
Evaluate substitutes to limit exposures or need for critical elements  
*Green chemistry initiatives* |
| End of Life         | Recycling/Re-use  
Disposal  
Mining Reclamation |
Case Example: Lanthanum

- **Case Study 1: Waste Effluents**
  - Complex extraction/processing procedures
  - Disposal practices not yet fully developed
  - Water quality or effluent standards do not exist

  - Effluent from a fluid cracking catalyst production plant has elevated La concentrations
  - Limited toxicity data suggestive of ecological impacts
  - Increased production may result in additional monitoring requirements for industry
Case Example: Indium

- Case Study 2: Occupational Exposure
  - Occupational exposure standards do not exist for most rare earth or specialty metals
  - Increased production of specialty metals increases chance for exposure
  - Indium is one of the few rare metals with occupational standards (0.1 mg/m³)
  - Indium tin oxide used in liquid crystal displays.
  - New study suggests lower OSHA standard.
  - Could result in more stringent regulation.
Case Example: Cerium

- Case Study 3: Product Safety
  - Increased production of specialty metals
    increases chance for exposure

  - Cerium oxide and nanoparticles are used to reduce carbon emissions in fuel
  - Small amounts of Ce are released during car emissions
  - As more fuels use additives, the more Ce will be released to the environment
  - Studies such as this explore the potential environmental impacts of increased releases of specialty metals
Environmental Issues

• Case Studies = are examples of possible issues that could be considered for any of the rare/specialty metals

• Additional analysis required (Risk Assessment)

  \[ \text{Exposure} \times \text{Hazard} = \text{Risk} \]

  › Evaluate magnitude of exposure
    • \textit{how much is released to the environment?}
    • \textit{how often are people/organisms exposed?}

  › Evaluate potential hazards
    • \textit{at what level/concentration are health or environmental effects expected?}

  › Evaluate data reliability
    • \textit{are exposure or toxicity data current, representative, qualified?}
Environmental Issues: Mining sites

- **Environmental Impacts From Mine Sites**
  - Soil impacts from tailings, impoundments, and processing facilities
  - Surface water and/or groundwater impacts from waste stream
  - Characterizing and controlling air emissions from operations
  - Impacts to vegetation and wildlife

- **Mitigating these issues requires**
  - Innovative technologies and approaches
  - Solutions that overcome regulatory barriers

- **However...**
  - Proactive approaches at new sites can avoid costly remediation
Environmental Issues: Mining sites

- **Acid Mine Drainage (AMD)**
  - Common metals mined from sulfide deposits include Zn, Pb, and Cu.
  - Tailings from these mine operations often contain pyrite ($\text{FeS}_2$).
  - When pyrite is exposed to air and water, an acidic solution is released.
  - Over 10,000 miles of US streams are impacted by AMD.
  - AMD affects both groundwater as well as surface water.
  - Often include high concentrations of other hazardous materials such as CN, and As.

\[
2\text{FeS}_2(\text{s}) + 7\text{O}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) \rightarrow 2\text{Fe}^{2+}(\text{aq}) + 4\text{SO}_4^{2-}(\text{aq}) + 4\text{H}^+(\text{aq})
\]

However, rare earths and many minor metals are often **not** associated with sulfide minerals.
Environmental Issues: Mining sites

- Potential environmental impacts from REM and minor metal mining activities
  - Refining of REO can produce:
    - Air emissions containing \( H_2SO_4 \) and/or HF
    - Acidic water, due to oxide deposits
    - Radioactive waste (Th, Ra, & U)
  - Some metals associated with sulfide deposits
    - (e.g., Cd, Hg), so AMD is still and issue
  - Complexity of separation and extraction techniques as well as the quantity of hazardous chemicals used in production
  - Some minor metals have known human health and environmental concerns of their own (e.g., As, Cd, Cr, Hg, and Se)
  - These are industrial facilities, such that industrial solvents and petroleum oils are used, and can be inadvertently released.
Case Examples: United States

• Case Study 1: Superfund Site in Oregon
  › Minor and rare earth metal extraction and refining from 1957 to Present
  › Main operation consisted of Zirconium (Zr) and Hafnium (Hf) extraction and refining from zircon sands. Also extracted and refined Tantalum (Ta), Niobium (Nb), Titanium (Ti), and Vanadium (V).
  › Contaminants of concern include: thorium, uranium, and radium; heavy metals; chlorinated solvents (MIBK, 111-TCA, PCE); and PCBs

• Case Study 2: Superfund Site in New Jersey
  › Interim Storage site for the extraction and refining of thorium and rare earth metals from monazite sands under US DOE contract from 1948 – 1971.
  › Contaminants of concern: thorium, uranium, and radium; heavy metals; and chlorinated solvents
Case Examples: International

• Case Study 3: Rare Earth processing Facility, Malaysia
  › From 1982 – 1994, processed monazite sands obtained from tin tailings to extract Yttrium, as well as rare earth chlorides and carbonates.
  › Waste piles contained elevated levels of Thorium and Radon
  › Site is linked to potential increased incidence of leukemia in the near by community of 11,000 people
  › Cleanup costs in excess of $100 million (US)

• Case Study 4: Rare Earth Mine, China
  › Since the 1970s processing of Pb mine tailings for REMs.
  › Impacts from Thorium, Uranium, and heavy metals to air, surface water, and groundwater.
  › Possible link to increased incidence of leukemia in the city of Baotou, China, a city with a population of 1.7 million people
Environmental Issues: Mining Sites

- **Regulating Mining Operations in the US**
  - Clean Water Act
  - Clean Air Act
  - CERCLA (aka – Superfund)
  - Mining in National Parks Act
  - Wild and Scenic Rivers Act

- **REM Regulatory Developments in the US and abroad**
  - US and Japan, in efforts to promote energy-efficiency, promoting research on rare earth mining and alternatives to rare earths.
  - US Science and Technology Council, Committee on Environment, Natural Resources and Sustainability will coordinate research into Rare Earths and other strategic elements.
  - European Union pursuing large scale recycling of Rare Earths and other strategic elements.
  - Chinese Ministry of Commerce will require companies that export Rare Earths to obtain ISO 9000 quality system certification and be equipped with environmental management equipment.

Environmental Issues: Conclusions

• Unique opportunities:
  › Study and evaluate potential environmental issues before they become environmental problems
  › Pro-actively perform environmental studies to prevent unintended risks, save money down the road
  › Evaluate new operations and new activities to ensure best practices are in place to promote safety to human health and the environment
  › Engage regulators early so that industry can help develop future regulations rather than react to them

• “Concern for man and his fate (environment) must always form the chief interest of all technical endeavors”. (Albert Einstein)
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