

Teaching Resources on the Sustainable Management of Critical Raw Materials

Trainer's Manual for Criticality

March 2020

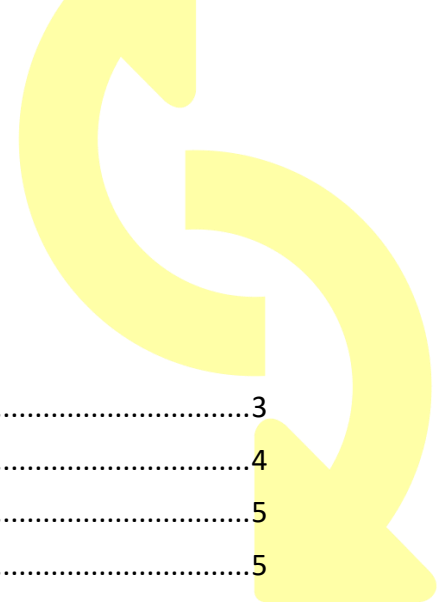
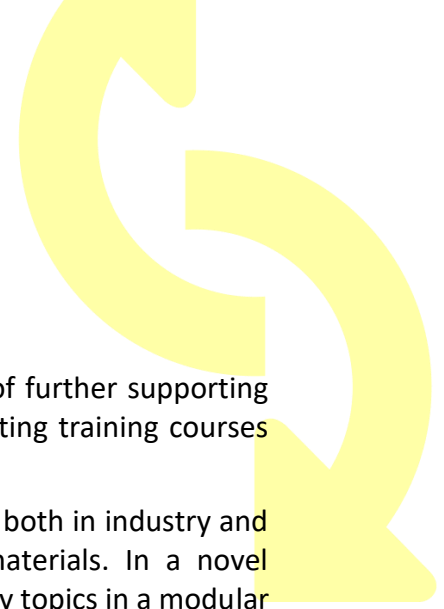


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1. Context and Introduction to Training

This booklet is supplementing the teaching materials and the set of further supporting booklets that have been developed to support teachers in conducting training courses related to the sustainable management of critical raw materials.

SusCritMat aims to educate people from Master's student level up, both in industry and academia about important aspects of sustainable critical raw materials. In a novel concept, it introduces courses on these complex and interdisciplinary topics in a modular structure, adaptable to a variety of different formats and accessible to both students and managers in industry. These courses will develop new skills, which will help participants to better understand the impact and role of critical raw materials in the whole value chain; enabling them to identify and mitigate risks. Understanding the bigger picture and the interconnected nature of global business and society is increasingly necessary to and valued by industry.

SusCritMat is an EU-funded project that brings together the technical and pedagogical expertise of leading educational institutions and business partners. It uses and creates teaching materials which can be combined into different course formats.

This training kit presents the key messages related with the sustainable management of critical raw materials in three major sections:

- Introduction to criticality (including criticality assessment, global resource supply chains, geopolitical factors, and economics of metals)
- Analysis of criticality (including material flows, scenario planning, and life cycle assessment)
- Solutions (including responsible sourcing, circularity indicators, circular product design, and good practice examples)

In particular, the solutions part will be in the focus. The intention is to underline the possibilities that are available to approach and implement a circular economy for critical raw materials and the products bearing these. Doing so the concrete actions, i.e. the things that can be done, are highlighted, instead of only mentioning all sorts of associated problems or barriers in the context of CRMs.

The overall goal of the Summer School for Educators is to qualify the participants to teach the topics themselves. Therefore, the school does not only provide an introduction and improved insight into selected thematic issues, but to also deliver a set of teaching materials "ready-to-use".

- Learning targets that will be reached after having taught the courses
- Presentations on the specific topics including also notes on how to present the slides and key messages.
- Group work exercises including the task or question to work on, if applicable further reading on the methodology and the solutions in case of tasks requiring calculations.
- Assessment questions and the correct answers for each specific topic.
- Additional reading for each topic.

1.1 Training Materials List

The *SusCritMat* project developed the following teaching materials for the Summer School:

Basics
Critical Resources for Emerging Technologies
Criticality
Supply Chain Resilience
Supply Risk Factors
Circularity
Circular Economy
Characterizing the Urban Mine
Circular Business Models
Waste Management and Recycling Potential
Closing Loops on Product Level
Governance
Geopolitical Aspects
Metals & CRM Scenarios
Restricted Substances Legislation
Impact on Society and the Environment
Sustainability Assessment
Responsible Mining
Responsible Sourcing / Certification
Environmental Aspects
Sustainable Materials Usage
CRM and Sustainable Development
Tools
MFA - Material Flow Management
Good Use of Data
LCA – Life Cycle Assessment
Process Models based on LCA

1.2 Suggested Timetable

The agenda contains a recommended timing for the lecture and exercises. However, depending on the pre-existing knowledge or group size the time can be extended.

Lecture: 45 minutes

Group work exercise: 30 minutes

Live quiz: 10 minutes

Discussion on quiz results: 15 minutes

1.3 Key Messages

Restrictions to the global supply for mineral raw materials (MRMs) are more related to ACCESS to MRMs than to geological availability (how much is out there).

Access is constrained by economic, geopolitical, environmental and social factors.

Criticality assessments are qualitative in nature: there is no “correct” method, but different methods are suited to different end users and scales of space and time.

A thorough market analysis, including information regarding ongoing mineral exploration projects, is often more informative than theoretical criticality calculations based on various formulae.

1.4 Learning Objectives

List the learning objectives for your course here.

This session will provide learners with:

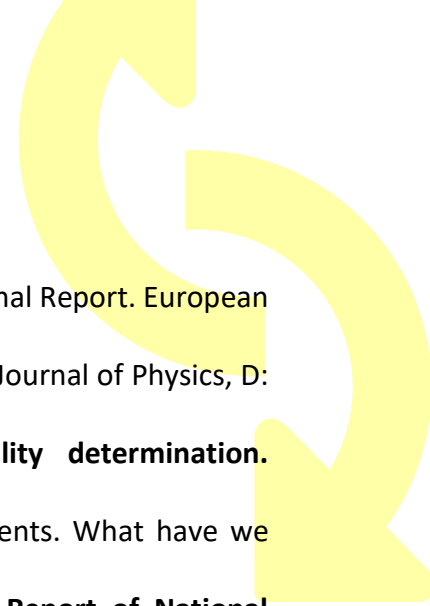
- A review of concepts underlying criticality assessments
- An overview of methodologies
- Clarify possibilities and limitations of criticality estimations
- Illustrations with reference to specific critical raw materials

1.5 Additional Reading

Literature list listed according to topics (**priority readings in bold**)

Blengini, G. A., et al., 2017. EU methodology for critical raw material assessment : Policy needs and proposed solutions for incremental improvements. Resources Policy, 53, 12-19.

Buijs, B., Sievers, H., Tercero Espinoza, L. 2012. Limits to the critical raw materials approach. Proceedings of the Institution of Civil Engineers - Waste and Resource Management, 165(4), 201-208.



EC, 2017. Study on the review of the list of Critical Raw Materials. Final Report. European Commission.

Frenzel et al., 2017. Raw material ‘criticality’ – sense or nonsense? Journal of Physics, D: Applied Physics, 50.

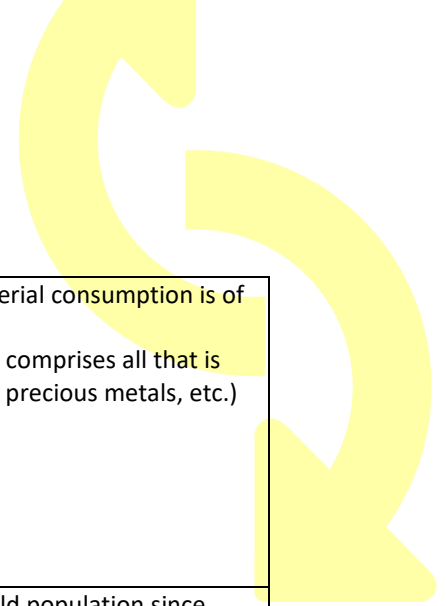
Graedel, T. E. et al., 2012. Methodology of metal criticality determination. Environmental Science & Technology, 46, 1063-1070.

Graedel, T. E. & Reck, B. K., 2016. Six years of criticality assessments. What have we learned so far? Journal of Industrial Ecology, 20(4), 692-699.

NRC, 2008. Minerals, Critical minerals, and the U.S. Economy. Report of National Research Council. Washington, DC: The National Academies Press.

2. Slides and Notes

<p>CRITICALITY CONCEPTS</p> <p>DOMINIQUE GUYONNET BRGM</p> <p><small>This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation.</small></p>	
<p>Course objectives</p> <ul style="list-style-type: none"> • Clarify the concepts underlying criticality assessments • Provide an overview of methodologies • Emphasize possibilities and limitations • Illustrate with reference to specific critical raw materials <p><small>© BRGM, 2019 2</small></p>	
<p>Contents</p> <ol style="list-style-type: none"> 1. Introduction: the increasing use of mineral raw materials 2. Factors influencing criticality 3. Overview of some criticality assessment methodologies 4. "Critical" about criticality 5. Conclusions <p><small>© BRGM, 2019 3</small></p>	



<p>1. Introduction : the increasing use of mineral raw materials</p> <ul style="list-style-type: none"> Main mineral raw materials consumed by a European in Kg/yr <p>© BRGM, 2019 4</p>	<p>The main mineral raw material consumption is of sand and gravel Other minerals and metals comprises all that is not indicated (rare metals, precious metals, etc.)</p>
<p>1. Introduction : the increasing use of mineral raw materials</p> <ul style="list-style-type: none"> Population growth? <p>© BRGM, 2019 5</p>	<p>Exponential growth of world population since industrial revolution, exploitation of fossil fuels, which enabled the agricultural revolution</p>
<p>1. Introduction : the increasing use of mineral raw materials</p> <ul style="list-style-type: none"> Mineral raw material consumption growing much faster than global population <p>© BRGM, 2019 6</p>	<p>We can't explain explosion of mineral raw material consumption only by population growth</p>
<p>1. Introduction : the increasing use of mineral raw materials</p> <ul style="list-style-type: none"> Rather: population growth + emergence of consuming class <p>Source : McKinsey and BRGM, World Materials Forum, June 2016 © BRGM, 2019 7</p>	<p>1: Historical values for 1820 through 1990 estimated by Homi Kharas, 2010 – 2025 estimates by McKinsey Global Institute 2: Defined as people with daily disposable income above \$10 at PPP. Population below consuming class defined as individuals with disposable income below \$10 at PPP (Power Purchasing Parity)</p>
<p>1. Introduction : the increasing use of mineral raw materials</p> <ul style="list-style-type: none"> Material consumption - example of Aluminium: how much additional Al production required to satisfy the 3 billion additional members of the consuming class between 2010 and 2030 (Brookings Institute)? If 3 billion people go from 1 kg Al/yr to 25 kg Al/yr, we need 72 Mt Al/yr extra (for reference: world Al production in 2017 was 60 Mt) <p>Source : USGS, 2010 © BRGM, 2019 8</p>	<p>Illustrates the significant difference between Industrialised versus emerging economies in terms of raw material consumption per capita.</p>

1. Introduction : the increasing use of mineral raw materials

- Need to account for increase of world demand by 2030

This activity has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska Curie Grant Agreement.

Graph also illustrates limits of exponential growth. This curve cannot be extended forever, due to environmental, social, energy, ... constraints

1. Introduction : the increasing use of mineral raw materials

- Reminder of the significance of exponential growth: growth rate versus doubling period

Rate (%)	1	2	3	4	5	7	10
Doubling period (years)	70	35	23	18	14	10	7

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Illustration: assuming we start (year 1) with a 100 ton/year production rate, we will have 200 tons/year in year 23 with a 3% growth rate, in year 14 with a 5% growth rate and in year 7 with a 10% growth rate.

1. Introduction : the increasing use of mineral raw materials

- Driver: Chinese metal consumption

Example of steel. Between 2001 and 2015: 12.7% annual growth!

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Key message : China has been a major driver of the World's economy and has consumed enormous amounts of mineral raw materials to fuel its growth.

1. Introduction : the increasing use of mineral raw materials

- Another essential driver: diversification of elements in products

Source: Reuter, M. et al.

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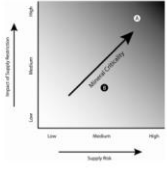

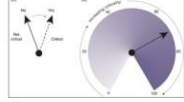



While during the 18th century, energy-producing technology used about 6 elements of the Mendeleiev Table, in the 21st century the technology uses about 50 elements.


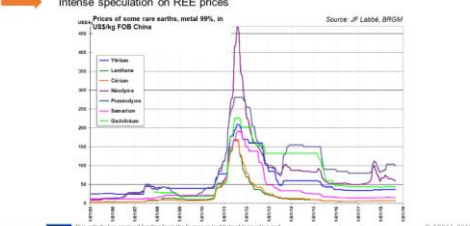
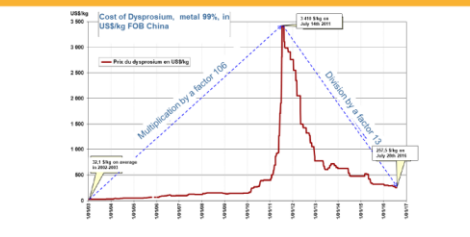


1. Introduction : the increasing use of mineral raw materials

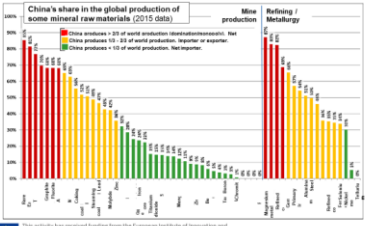



- MRMs for the energy sector

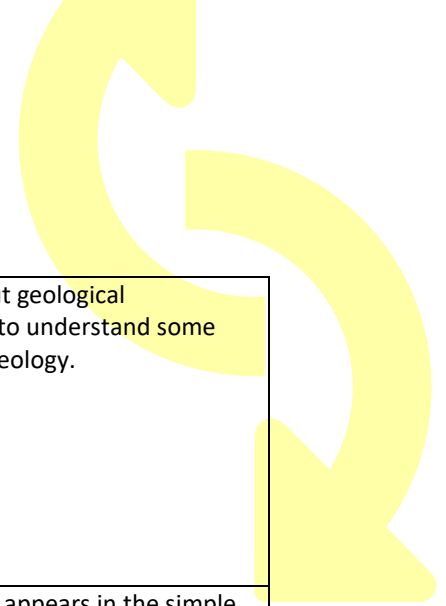
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The same message as previously is illustrated, in more detail, by this slide. Nearly all the elements of Mendeleiev's Table are involved in the production of energy.

<p>2. Factors influencing criticality</p> <ul style="list-style-type: none"> The term « Mineral Criticality » starts to appear in the years 2000 in US documents; e.g.: National Research Council report 2007 « Minerals, Critical Minerals and the U.S. Economy »:  <ul style="list-style-type: none"> In the latter, criticality assessment is performed in a 2-dimensional matrix: <ul style="list-style-type: none"> Supply risk Impact of Supply Restriction A mineral is considered « critical » if it scores high in this matrix in a relative sense: mineral A is considered more critical than mineral B Most methods adopt a 2-D matrix <p><small>This activity has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska Curie Grant. © BRGM, 2019 14</small></p>	<p>A critical mineral or raw material is (i) important for one or several industrial sectors and (ii) is at risk of supply shortage.</p>
<p>2. Factors influencing criticality</p> <ul style="list-style-type: none"> EU method tends to be dichotomous: a MRM is either « critical » or « non-critical », according to a threshold  <ul style="list-style-type: none"> Some authors argue that criticality is not binary (a), but rather a question of degree (b)  <p><small>Source: Critical Metals Handbook</small></p> <p><small>This activity has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska Curie Grant. © BRGM, 2019 15</small></p>	<p>There is no unambiguous criticality threshold. It is a question of choice.</p>
<p>2. Factors influencing criticality</p> <ul style="list-style-type: none"> Time factor  <p>Spot the car in 1900</p> <p><small>Source: Tony Sides, US National Archives, in: S. Friedland, World Minerals Forum, 2017</small></p> <p><small>This activity has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska Curie Grant. © BRGM, 2019 16</small></p>	<p>There was only one motor vehicle on 5th avenue on April 15th 1900</p>
<p>2. Factors influencing criticality</p> <ul style="list-style-type: none"> Spot the horse in 1913  <p><small>Source: Tony Sides, US National Archives, in: S. Friedland, World Minerals Forum, 2017</small></p> <p><small>This activity has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska Curie Grant. © BRGM, 2019 17</small></p>	<p>While on March 23rd 1913, only 13 years later, there was only one horse-driven carriage</p>
<p>2. Factors influencing criticality</p> <ul style="list-style-type: none"> Scale factor – criticality differs at different scales <p>e.g.</p>  <p><small>This activity has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska Curie Grant. © BRGM, 2019 18</small></p>	<p>A specific industry, in a specific country, will have supply-chain risks that are very different from those of an entire country or of a continent. Therefore criticality is a relative notion.</p>

<p>2. Factors influencing criticality</p> <ul style="list-style-type: none"> • Geopolitical factor - risk of supply disruption ✓ e.g. CN-JP territorial dispute over Senkaku islands ✓ In 2010 CN enforced stricter export quotas on REEs and blocked exports to JP  <p>Evolution of Chinese REE export quotas from 2005 to 2012, in metric tonnes</p> <p>Data source: US Congress, research.uscib.gov, March 2012</p> <p>© BRGM, 2019 19</p>	<p>Both China and Japan claim sovereignty over the Senkaku islands. In 2010 the dispute climaxed which led to retaliatory measures from China, who blocked all rare earth exports to Japan.</p>
<p>2. Factors influencing criticality</p> <ul style="list-style-type: none"> → Intense speculation on REE prices  <p>Prices of some rare earths, metal 99%, in US\$/kg FOB China</p> <p>Source: JF Labbe, BRGM</p> <p>© BRGM, 2019 20</p>	<p>Prices of rare earth metals (here so-called « Light » rare earths) skyrocketed</p>
<p>2. Factors influencing criticality</p>  <p>Cost of Dysprosium, metal 99%, in US\$/kg FOB China</p> <p>Multiplication by a factor 100</p> <p>1,400 \$/kg in 2010 (100x)</p> <p>200 \$/kg in 2015 (10x)</p> <p>Division by a factor 10</p> <p>© BRGM, 2019 21</p>	<p>This one shows a Heavy Rare Earth (Dysprosium: an essential component of permanent magnets).</p>
<p>2. Factors influencing criticality</p> <ul style="list-style-type: none"> • Attempts to escape from the Chinese monopoly: ✓ Mountain Pass (USA) : company Molycorp reopened in 2012 after prolonged inactivity. Went bankrupt because of low prices and closed in 2015. Mining has resumed since Jan 2018. ✓ Mount Weld (Australia) : Company LYNAS. Survived thanks to « offtake » contracts.  <p>24Mt @ 7.8% REO ⇨ 1.87 Mt REO</p> <p>Source : J. Tabari</p> <p>© BRGM, 2019 22</p>	
<p>2. Factors influencing criticality</p>  <p>MOLYCORP stock</p> <p>LYNAS stock</p> <p>© BRGM, 2019 23</p>	<p>Illustrates the « speculation bubble » effect. China has different (long term) strategy, not so dependent on short-term market performance</p>

<p>2. Factors influencing criticality</p> <p>• Production Concentration factor</p> <p>China's share in the global production of some mineral raw materials (2015 data)</p>  <p>Source: JF Labbe, BRGM</p>	<p>Illustrates importance of value chain: some countries may be key players in refining but not in mining</p>
<p>2. Factors influencing criticality</p> <p>✓ An indicator of market concentration: the Herfindahl-Hirschman index:</p> $HHI = \sum_{i=1}^n s_i^2$ <p>where s_i is country « i »'s share in world production and « n » is the number of country's producing the raw material.</p> <p>✓ So if 2 countries have an equal share of the market: $HHI = 0,5^2 + 0,5^2 = 0,25 + 0,25 = 0,5$</p> <p>✓ HHI varies between $1/n$ (equal shares between n countries) and 1 (total concentration in one country).</p> <p>✓ Often the actual percent values (eg. 5 for 5%) are used and then HHI varies between 10 000/n and 10 000</p> <p>© BRGM, 2019 24</p>	
<p>2. Factors influencing criticality</p> <p>Ranking (used in finance) :</p>  <ul style="list-style-type: none"> ✓ $HHI < 0,01$ (or 100): Highly competitive market (very well distributed production) ✓ $0,01$ (or 100) $< HHI < 0,15$ (or 1 500): Unconcentrated production ✓ $0,15$ (or 1 500) $< HHI < 0,25$ (or 2 500): Moderate concentration ✓ $HHI > 0,25$ (or 2 500): High concentration <p>Proposal:</p> <ul style="list-style-type: none"> ✓ $HHI > 0,5$ (or 5 000): Very high concentration (monopoly) <p>© BRGM, 2019 25</p>	<p>The proposal is relevant for some strategic metals (see Hands On exercise)</p>
<p>2. Factors influencing criticality</p> <p>• Good Governance</p> <ul style="list-style-type: none"> ○ A country with poor governance is less reliable in terms of supply than a country with good governance ○ The World Governance Index (WGI) is an indicator developed in 2008 by the Forum for a new World Governance (FnWG) ○ It aims to provide, each year, an image of the situation of world governance ○ The index is based on several indicators. One of these indicators (political stability) is used in a criticality calculation methodology (Yale methodology, see below)  <p>© BRGM, 2019 27</p>	<p>Political stability is a key indicator in the evaluation of criticality, as it has a strong influence on supply risk.</p>
<p>2. Factors influencing criticality</p> <p>• Geological availability factor</p> <p>A source of misunderstanding among the general public</p>  <p>Basis of calculation : $\frac{\text{Reserve Base (tons)}}{\text{Production (tons/yr)}}$</p> <p>New Scientist, 2007</p> <p>© BRGM, 2019 28</p>	<p>This graphic, published in the media, claims to provide the number of years until several mineral raw materials « run out »</p>



2. Factors influencing criticality

- Part of the misunderstanding comes from the confusion between resources and reserves
- Some definitions (based on JORC; Joint Ore Reserves Committee, 2012) :
 - Mineral resources are concentrations or mineralizations of natural substances present in the earth's crust (to form a deposit) which present certain characteristics of quantity, quality, etc., such that there are reasonable prospects for economic extraction of these substances
 - Ore reserves are a portion of mineral resources for which it has been proven that it is economically, technically and legally feasible to extract the ore

Note: there was a major effort in terms of classification in the aftermath of the Bre-X scandal (Busang, Indonesia, 1997)

This activity has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska Curie Grant agreement No. 101019718.

In order to talk sense about geological availability, it is necessary to understand some basic concepts of mining geology.

2. Factors influencing criticality

General relationship between exploration results, mineral resources and ore reserves (JORC, 2012)

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The « Reserve Base », that appears in the simple calculation of mineral depletion time, is estimated from indicated and measured mineral resources. This depends on the level of mineral exploration: it is definitely not « all that's out there »

2. Factors influencing criticality

Resources / Reserves schematic

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2. Factors influencing criticality

- Relationship between tonnage and cutoff grade
- As metal price increases, cutoff grade decreases and so ore reserves (tonnage) increase (what was not economic becomes economic)

Grade-Tonnage Curve for the Makapela Gold Prospect

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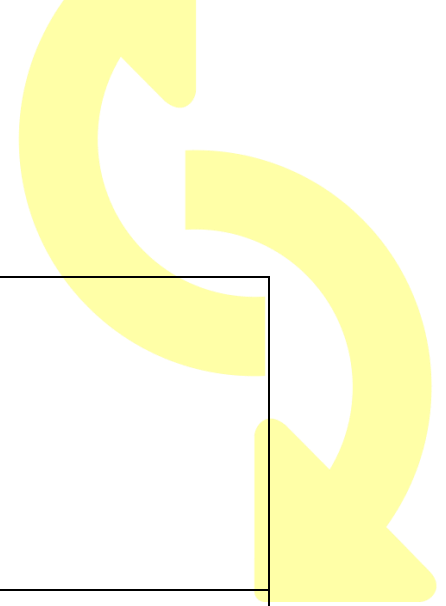
The cutoff grade is the ore grade (concentration) below which the miner decides not to extract because he won't make a profit

2. Factors influencing criticality



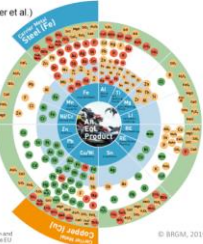
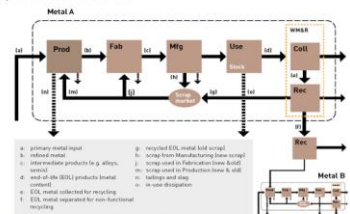
"Estimating what's left to extract based on the "Reserve Base" is analogous to estimating what you have left to eat based on what's left in your refrigerator"

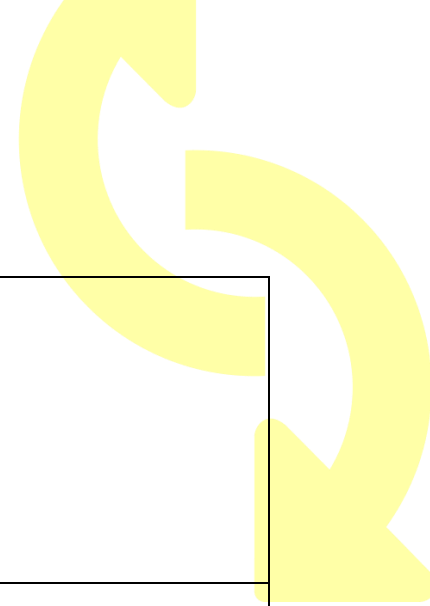
(source: a mining geologist)

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<p>2. Factors influencing criticality</p> <p>Comments on the « mineral resource depletion » issue</p> <ul style="list-style-type: none"> The « peak metal » / « fixed stock » approach is not valid: the reserve base is changing all the time. The issue is much less « Mineral resource depletion » than « access to mineral resources » This access is constrained by many factors (production concentration, geopolitical risks, environmental constraints, social acceptability, aversion to financial risk of investment banks, ...) While there may still be ore to mine out there, it is becoming increasingly difficult to mine due to decreasing ore grades (need more energy to get the stuff out) Although in the short to medium term, primary resources will continue to be the main source of mineral raw materials, recycling, reuse, substitution, etc. must be developed, to reduce waste flows and offset emissions related to primary resource extraction Recycling can help offset depletion, but not if we continue increasing consumption at such rates <p><small>This activity has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101019719. © BRGM, 2019 34</small></p>	
<p>2. Factors influencing criticality</p> <ul style="list-style-type: none"> Objective: resource efficiency. Reduce mineral raw material consumption per service while reducing environmental impacts (environmental rucksack) <p>water, rock, energy, chemicals, land area, biodiversity, risks, ... (+ economic & social...)</p> <p>Ecological Rucksack</p> <p><small>This activity has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101019719. © BRGM, 2019 35</small></p>	
<p>2. Factors influencing criticality</p> <ul style="list-style-type: none"> Ore grade factor <p>Declining ore grades: gold (Mudd, 2009)</p> <p><small>This activity has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101019719. © BRGM, 2019 36</small></p>	<p>Over time, miners have progressively mined mineral deposits with lower and lower ore grades (metal concentrations). Because they mined the richest deposits first.</p>
<p>2. Factors influencing criticality</p> <p>Same for copper</p> <p>Global weighted average copper mine ore head grade (% of Cu)</p> <p>Source: Brook Hunt, Barclays Research</p> <p><small>This activity has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101019719. © BRGM, 2019 37</small></p>	<p>Same holds for copper. There will come a point, where the metal concentration in the ore will be so low that it won't be worth mining anymore (cost of energy required to mine will be too high).</p>
<p>2. Factors influencing criticality</p> <ul style="list-style-type: none"> Environmental factor <p>Mine waste production in Australia Source: Gavin Mudd</p> <p><small>This activity has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101019719. © BRGM, 2019 38</small></p>	<p>When a miner extracts ore, he is extracting a small percentage of metal (for example copper) and a large percent of mine waste (see course on responsible mining). Mine waste represents an environmental hazard.</p>

<p>2. Factors influencing criticality</p>  <p>Source - National Geographic</p> <p><small>This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the European EIT, the EIT Partnership Programme for Research and Innovation</small></p> <p><small>© BRGM, 2019 39</small></p>	<p>This photo shows the impressive scale of mine waste generation in the extractive industry</p>
<p>2. Factors influencing criticality</p> <ul style="list-style-type: none"> Social factor  <p><small>This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the European EIT, the EIT Partnership Programme for Research and Innovation</small></p> <p><small>© BRGM, 2019 40</small></p>	<p>The « Social Licence to Operate » of the mining industry is seriously under pressure, especially in the wake of major accidents such as the Brumadinho tailings facility accident in January 2019 (200 casualties).</p>
<p>2. Factors influencing criticality</p> <ul style="list-style-type: none"> Industry structure factor - the « metal wheel » (M. Reuter et al.) <p>Importance of base metal metallurgy for recovery of smaller metals (and for recycling)</p>  <p><small>This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the European EIT, the EIT Partnership Programme for Research and Innovation</small></p> <p><small>© BRGM, 2019 41</small></p>	<p>« Rich » graphic although difficult to read. Key message is that many critical metals are not produced for themselves but as byproducts of « carrier metals »</p>
<p>2. Factors influencing criticality</p> <ul style="list-style-type: none"> must keep in mind the value chain  <p>Source : UNEP, 2011</p> <p><small>This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the European EIT, the EIT Partnership Programme for Research and Innovation</small></p> <p><small>© BRGM, 2019 42</small></p>	<p>Metal B is non-functional recycling: metal A is downcycled and is no longer recycled for its specific properties. All explanations are in the UNEP 2011 report. Metal Recycling Opportunities, Limits, Infrastructure.</p>
<p>2. Factors influencing criticality</p> <p>In summary</p> <ul style="list-style-type: none"> Criticality assessment is a form of Risk Assessment Risk is the potential for losing something of value. In the case of CRMs, the value can be: <ul style="list-style-type: none"> economic wealth, job loss, deterioration of social fabric, infrastructure, know-how, energy management, ... Risk assessment traditionally consists in evaluating two components of risk: <ul style="list-style-type: none"> the magnitude of the loss probability that the loss will occur There are quantitative and qualitative risk assessments (see for ex. the European methodology for contaminated soil risk assessments) Criticality assessments are somewhere in-between (semi-quantitative risk assessments) <p><small>This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the European EIT, the EIT Partnership Programme for Research and Innovation</small></p> <p><small>© BRGM, 2019 43</small></p>	



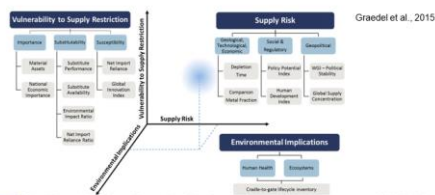
3. Overview of some methodologies

- **Yale methodology**
 - ✓ Geographical focus: United States (corporate, national and global levels)
 - ✓ Extension of the U.S. National Research Council studies started in 2006
 - ✓ Definitions of criticality according to 3 dimensions (Graedel et al., 2011):
 - Supply risk
 - Vulnerability to Supply Restriction
 - Environmental implications
 - ✓ **Progressive** approach to define a "degree" of criticality of the MRM
 - ✓ **Criticality Assessment**: a score is attributed to several indicators resulting in a position in a 3-D criticality space

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3. Overview of some methodologies

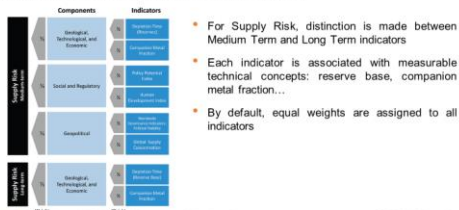
- ✓ Various indicators are related to each one of the 3 dimensions



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3. Overview of some methodologies

- **Criticality Assessment results depend on the choice of indicators**

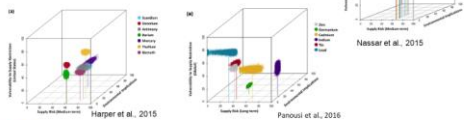


- For Supply Risk, distinction is made between Medium Term and Long Term indicators
- Each indicator is associated with measurable technical concepts: reserve base, companion metal fraction...
- By default, equal weights are assigned to all indicators

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3. Overview of some methodologies

- Methodology intended to allow flexibility among potential users and different organizational levels (corporate, national, global)
- Examples published in the Journal of Industrial Ecology:
 - ✓ REEs
 - ✓ Zinc, Tin, and Lead Family elements
 - ✓ Seven specialty metals (Ba, Bi, Hg, Sc, Sr, Sb, Ti)

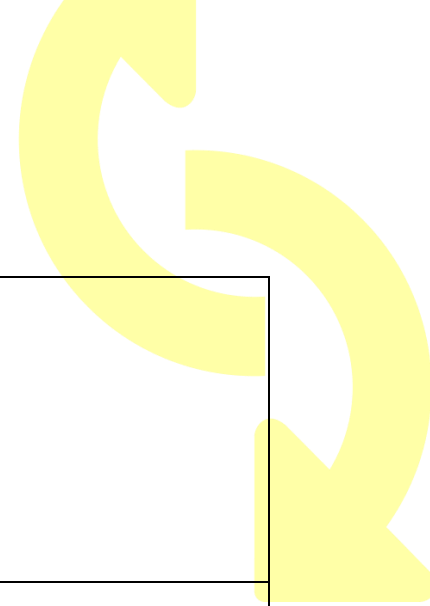


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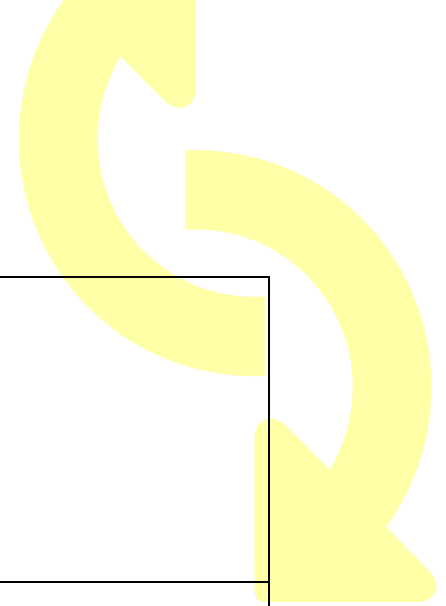
3. Overview of some methodologies

- **EU methodology**
 - ✓ Geographical focus: European Union
 - ✓ 3 Criticality Assessment studies to-date: 2010, 2014, 2017
 - ✓ Definitions of criticality according to 2 dimensions
 - Economic importance to the EU (EI)
 - Vulnerability to supply disruption (Supply Risk; SR)
 - ✓ **Dichotomous** approach : a raw material is either « critical » or « non-critical », according to a threshold defined by the Joint Research Center (JRC)
 - ✓ A criticality score is calculated for each Raw Material using the same parameters and equations

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<h3>3. Overview of some methodologies</h3> <ul style="list-style-type: none"> 2017 methodology revision was motivated by the need to: <ul style="list-style-type: none"> Better capture risks of trade distortion such as: <ul style="list-style-type: none"> Export taxes Physical quotas Export prohibitions Address more adequately the entire value chain (identify bottlenecks in the steps of extraction or metallurgy, shifts in supply concentration, etc.) Differentiate Global supply and European supply Better account for supply from secondary sources and for substitution potentials Have a more transparent allocation of raw material uses to NACE sectors <p><small>This activity has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska Curie Grant agreement No. 101019719. © BRGM, 2019 49</small></p>	
<h3>3. Overview of some methodologies</h3> <ul style="list-style-type: none"> In 2017, the measure of Economic Importance (EI) was calculated from: $EI = \frac{10}{Q_{max}} \sum A_i Q_i S_{Lij}$ <p>Where: A_i = share of metal demand in application "i" relative to total demand Q_i = Gross Value Added (GVA) of 2-digit NACE sector allocated to application "i" Q_{max} = Largest GVA of all 2-digit NACE sectors (scaling factor) S_{Lij} = Substitutability Index related to Economic Importance</p> Supply Risk (SR) was calculated from: $SR = \left[\frac{(HHI_{GSI} - 1) \cdot IR}{2} + \frac{(HHI_{GSI} - 1) \cdot IR}{2} \right] (1 - EOL_{RIS}) S_{Lij}$ <p>Where: $(HHI_{GSI})_{2017}$ = Herfindahl-Hirschmann Index for Global Supply, taking into account World Governance index score and a trade factor (t) $(HHI_{GSI})_{2014}$ = Herfindahl-Hirschmann Index for EU 28 Supply, taking into account World Governance index score and a trade factor IR = Import Reliance (%) EOL_{RIS} = End of Life-recycling input rate S_{Lij} = Substitutability Index related to Supply Risk</p> <p><small>This activity has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska Curie Grant agreement No. 101019719. © BRGM, 2019 50</small></p> 	
<h3>3. Overview of some methodologies</h3> <p>EU CRM list 2010</p> <p><small>This activity has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska Curie Grant agreement No. 101019719. © BRGM, 2019 51</small></p>	
<h3>3. Overview of some methodologies</h3> <p>EU CRM list 2014</p> <p><small>This activity has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska Curie Grant agreement No. 101019719. © BRGM, 2019 52</small></p>	
<h3>3. Overview of some methodologies</h3> <p>EU CRM list 2017</p> <p><small>This activity has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska Curie Grant agreement No. 101019719. © BRGM, 2019 53</small></p>	



3. Overview of some methodologies

Question: why does Scandium have more Economic Importance than Lithium?

Commodity name	Strategic importance	Supply risks	Strategic importance	Supply risks	Strategic importance	Supply risks
Aluminum	1.0	1.0	1.0	1.0	1.0	1.0
Antimony	1.0	1.0	1.0	1.0	1.0	1.0
Asphalt	1.0	1.0	1.0	1.0	1.0	1.0
Barium	1.0	1.0	1.0	1.0	1.0	1.0
Bismuth	1.0	1.0	1.0	1.0	1.0	1.0
Boron	1.0	1.0	1.0	1.0	1.0	1.0
Bromine	1.0	1.0	1.0	1.0	1.0	1.0
Caesium	1.0	1.0	1.0	1.0	1.0	1.0
Chromium	1.0	1.0	1.0	1.0	1.0	1.0
Cobalt	1.0	1.0	1.0	1.0	1.0	1.0
Copper	1.0	1.0	1.0	1.0	1.0	1.0
Fluorine	1.0	1.0	1.0	1.0	1.0	1.0
Germanium	1.0	1.0	1.0	1.0	1.0	1.0
Gold	1.0	1.0	1.0	1.0	1.0	1.0
Graphite	1.0	1.0	1.0	1.0	1.0	1.0
Indium	1.0	1.0	1.0	1.0	1.0	1.0
Iridium	1.0	1.0	1.0	1.0	1.0	1.0
Iron	1.0	1.0	1.0	1.0	1.0	1.0
Lead	1.0	1.0	1.0	1.0	1.0	1.0
Lithium	1.0	1.0	1.0	1.0	1.0	1.0
Mercury	1.0	1.0	1.0	1.0	1.0	1.0
Molybdenum	1.0	1.0	1.0	1.0	1.0	1.0
Nickel	1.0	1.0	1.0	1.0	1.0	1.0
Platinum	1.0	1.0	1.0	1.0	1.0	1.0
Platinum Group Metals	1.0	1.0	1.0	1.0	1.0	1.0
Rare Earth Elements	1.0	1.0	1.0	1.0	1.0	1.0
Rhenium	1.0	1.0	1.0	1.0	1.0	1.0
Rubidium	1.0	1.0	1.0	1.0	1.0	1.0
Selenium	1.0	1.0	1.0	1.0	1.0	1.0
Silver	1.0	1.0	1.0	1.0	1.0	1.0
Sulfur	1.0	1.0	1.0	1.0	1.0	1.0
Tantalum	1.0	1.0	1.0	1.0	1.0	1.0
Tellurium	1.0	1.0	1.0	1.0	1.0	1.0
Tin	1.0	1.0	1.0	1.0	1.0	1.0
Titanium	1.0	1.0	1.0	1.0	1.0	1.0
Tungsten	1.0	1.0	1.0	1.0	1.0	1.0
Vanadium	1.0	1.0	1.0	1.0	1.0	1.0
Zinc	1.0	1.0	1.0	1.0	1.0	1.0
Zirconium	1.0	1.0	1.0	1.0	1.0	1.0

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3. Overview of some methodologies

- According to USGS, the global supply and consumption of Sc is around 10-15 tons per year.
- Scandium uses in 2016:
 - The main uses were in Al-Sc alloys and in solid oxide fuel cells (SOFC)
 - Al-Sc alloys are produced for sporting goods (luxury golf clubs)
 - Al-Sc alloys are considered a potential substitute for Titanium (expensive) in e.g. aircrafts. But this is currently at R&D stage and no aircraft industry would suffer from Sc-supply disruption
 - Sc is used in small quantities in a number of electronic applications
 - Other minor uses: ceramics, lasers, lighting, ...
- So Scandium is a **niche market**



See hands-on exercise...

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3. Overview of some methodologies

- Some advantages of the EU Criticality assessment methodology**
 - Important communication tool for policy makers and (some) industrial companies
 - Transparency of the methodology and sources of data
 - Snapshot of the parameters affecting criticality of each specific Raw Material (at the time of the study), described in the additional Factsheets.
- Some drawbacks of the EU Criticality assessment methodology**
 - Complexity of the formulas and constraints imposed by transparency (e.g. use of public data only) are not always compatible with the complexity of the markets at stake
 - Some parameters affecting criticality are omitted (see hands-on exercise)

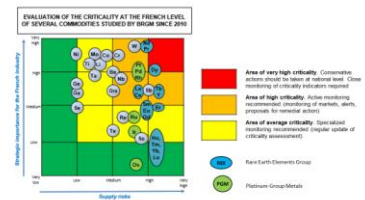
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3. Overview of some methodologies

- BRGM methodology**
 - Geographical focus: France
 - Criticality Assessment studies : About 20 CRM covered from 2010 to 2017, according to French governments' requests and priorities
 - Definitions of criticality according to 2 dimensions :
 - Strategic importance for the French industry (y-axis)
 - Supply risks (x-axis)
 - Progressive approach :
 - Not one but several thresholds to define the degree of exposure to the risks
 - No calculation but rather an indicative position based on several parameters and expert judgement
 - The objective is to give criticality indicators to policy makers and industry, as well as recommendations of actions to carry out

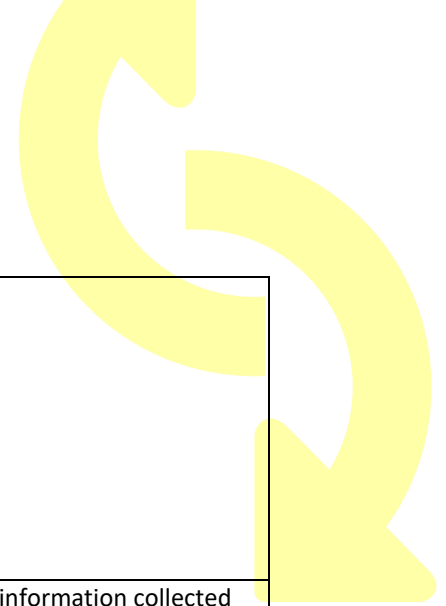
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3. Overview of some methodologies



Source : BRGM, 2017

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3. Overview of some methodologies

- ✓ Criticality assessments follow a detailed list of indicators :
 - Evolution of use and consumption
 - Evolution of world production and known resources / reserves
 - Substitution
 - Recycling
 - Prices
 - Restrictions to international trade, regulations
 - French production and resources
 - French industrial sector
 - External trade and French consumption
 - Other

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This illustrates the type of information collected to study a metal's criticality. Why is it important? Which industrial sectors use it? In what type of products? Etc.

3. Overview of some methodologies

World uses of Tungsten in 2015

Distribution of tungsten users by industrial sector

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This illustrates the type of information collected to study a metal's criticality. Why is it important? Which industrial sectors use it? In what type of products? Etc.

3. Overview of some methodologies

Historical trends

Mine production by country

Evolution of prices

Production average annual growth rate :

- 2010 - 2015 : 2%
- 1996 - 2015 : 5%
- 1915 - 2016 : 2,82%

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Which countries are producing it? How are the prices evolving?

3. Overview of some methodologies

Tungsten current production and reserves

World mine production in 2015

Distribution of known world reserves in 2016

✓ 3 Mt reserves are equivalent to 35 years of production at the 2015 level (88 kt W).
 ✓ With a 2% production annual growth rate (as observed since 2010), these reserves would be depleted in 26 years

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What are the known « geological stocks »? Where are they located in the world?

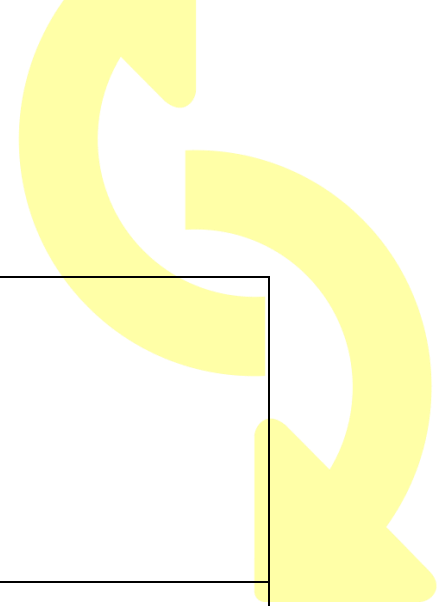
3. Overview of some methodologies

W: synthesis of criticality factors

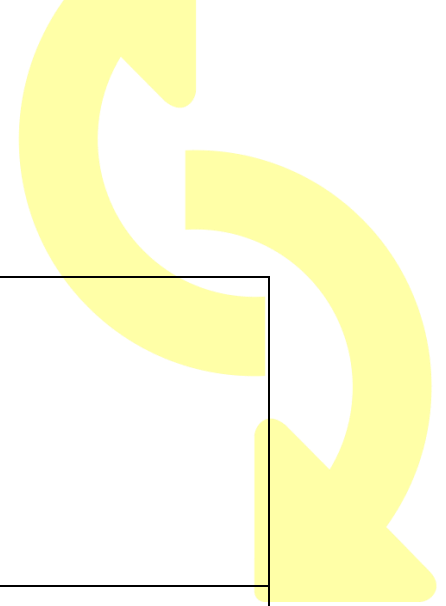
Quantitative and geographical concentration of reserves and reserves	Geographical concentration of mines and reserves	Restrictions to the trade of raw material	Specific environmental issues	Geographical concentration of metallurgy	Economic impacts to the extent of supply
Reserve world resources amount to approx. 75 years of world production of 88 ktW. China has 65% of world reserves. Significant resources exist worldwide.	80% of primary world production is in China. The production of 88 ktW is concentrated in a few countries, with China controlling the transformation of these and concentration into intermediate products.	China is the largest producer, particularly tungsten. Production is concentrated in a few countries, with China controlling the transformation process and concentration into intermediate products.	Tungsten and China. Tungsten is difficult to substitute because of its very high hardness (HRC 60-65) and resistance to high temperatures. The metallurgical structure in the world (including France, USA, Japan, etc.)	Tungsten is difficult to substitute because of its very high hardness (HRC 60-65) and resistance to high temperatures. The metallurgical structure in the world (including France, USA, Japan, etc.)	Tungsten is difficult to substitute because of its very high hardness (HRC 60-65) and resistance to high temperatures. The metallurgical structure in the world (including France, USA, Japan, etc.)

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The BRGM methodology is a multi-factor analysis, where scores are assigned to factors that influence criticality.






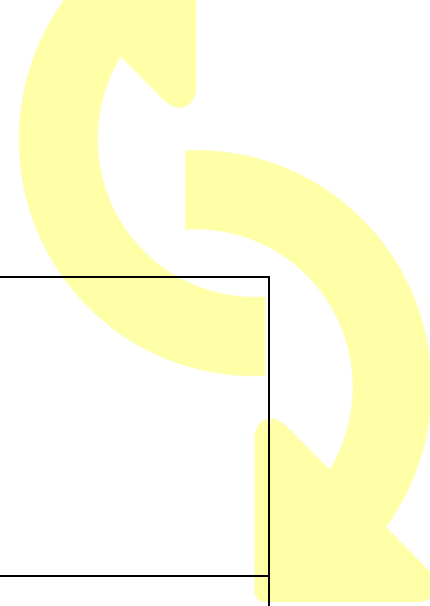
<h3>3. Overview of some methodologies</h3> <ul style="list-style-type: none"> Conclusion: very high criticality of Tungsten (W) at the French level due in particular to: <ul style="list-style-type: none"> The wide variety of uses in industry (e.g. Tungsten carbide tools) The strong dominance of China over the global market <p>Source: BRGM, MinerInfo.fr</p> <p><small>The activity has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska Curie Grant Agreement. © BRGM, 2019 64</small></p>	
<h3>4. Critical about criticality</h3> <ul style="list-style-type: none"> Several critical appraisals of criticality assessment methodologies in the literature. For example: <ul style="list-style-type: none"> <p>Raw material 'criticality'—sense or nonsense?</p> <p>Wenzel T., J. Kuehn U. & Breyer M. & G. G. G. G.</p> This paper advocates a more "quantitative" approach to risk in criticality assessments. Difficulty: due to abovementioned diversity/complexity of risk factors, it is difficult to build a comprehensive quantitative "model" of factor interactions <p><small>The activity has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska Curie Grant Agreement. © BRGM, 2019 65</small></p>	
<h3>4. Critical about criticality</h3> <ul style="list-style-type: none"> Criticality is a dynamic, ever-changing characteristic of a MRM. Therefore assessments need to be periodically updated Regarding methodologies, we feel there should be more scope for feedback from industry/expert stakeholders before issuing CRM assessment results Before performing a criticality assessment, key questions are: <ul style="list-style-type: none"> Critical for who? Critical for what? (decision-making) Past experience has shown benefits of criticality analyses especially at a corporate level. In particular when analyses have led to actions in terms of reducing company exposure to problematic elements Scope for a harmonized methodology?... Addressing uncertainties?... <p><small>The activity has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska Curie Grant Agreement. © BRGM, 2019 66</small></p>	
<h3>4. Critical about criticality</h3> <ul style="list-style-type: none"> Other example: Buijs et al. (see references). These authors identify the following limitations in the critical minerals approach: <ul style="list-style-type: none"> Bias towards technology minerals by emphasizing (a) high-tech applications and (b) the role of market power of producers in small markets, Lack of predictive power beyond the short term, Failure to distinguish between short-term and long-term problems, Tendency to overstate the economic impact of a possible supply disruption of 'critical' minerals, Exaggerated focus on risks related to the mining and export of raw materials, but not on the larger production chain (e.g. refining, transport, and trade in semi-products). According to the authors, most of the minerals that historically have been classified as "critical", have in fact never caused significant problems (e.g. PGMs). An issue specific to the EC method will be addressed during the "hands-on" session <p><small>The activity has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska Curie Grant Agreement. © BRGM, 2019 67</small></p>	
<h3>4. Critical about criticality</h3> <ul style="list-style-type: none"> Example of CRM list for specific applications: <ul style="list-style-type: none"> <p>Critical Metals in the Path towards the Decarbonisation of the EU Energy Sector</p> <p>Assessing their Role as Supply Chain Bottlenecks in Low-Carbon Energy Technologies</p> <p>Michael A. Brown, Michael J. Graedel, Christy M. M. M. M. M.</p> <p><small>The activity has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska Curie Grant Agreement. © BRGM, 2019 68</small></p>	



<h3>4. Critical about criticality</h3> <p>Illustrates importance of time factor: in 2013, Eu, Tb were considered highly critical</p> <table border="1"> <thead> <tr> <th>High</th> <th>High-Medium</th> <th>Medium</th> <th>Medium-Low</th> <th>Low</th> </tr> </thead> <tbody> <tr> <td>REE: Eu, Tb, Y</td> <td>Graphite</td> <td>REE: La, Ce, Sm, Gd</td> <td>Lithium</td> <td>Nickel</td> </tr> <tr> <td>REE: Pr, Nd</td> <td>Rhenium</td> <td>Cobalt</td> <td>Molybdenum</td> <td>Lead</td> </tr> <tr> <td>Gallium</td> <td>Hafnium</td> <td>Tantalum</td> <td>Selenium</td> <td>Gold</td> </tr> <tr> <td>Tellurium</td> <td>Germanium</td> <td>Niobium</td> <td>Silver</td> <td>Cadmium</td> </tr> <tr> <td></td> <td>Platinum</td> <td>Vanadium</td> <td></td> <td>Copper</td> </tr> <tr> <td></td> <td>Indium</td> <td>Tin</td> <td></td> <td></td> </tr> <tr> <td></td> <td></td> <td>Chromium</td> <td></td> <td></td> </tr> </tbody> </table> <p>Source: JRC, 2013</p> <p><small>This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation. © BRGM, 2019 69</small></p>	High	High-Medium	Medium	Medium-Low	Low	REE: Eu, Tb, Y	Graphite	REE: La, Ce, Sm, Gd	Lithium	Nickel	REE: Pr, Nd	Rhenium	Cobalt	Molybdenum	Lead	Gallium	Hafnium	Tantalum	Selenium	Gold	Tellurium	Germanium	Niobium	Silver	Cadmium		Platinum	Vanadium		Copper		Indium	Tin					Chromium			
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<h3>4. Critical about criticality</h3> <p>But: fluorescent lighting has been rapidly superseded by LEDs</p> <p>Overseas market demand in million units</p> <p>Source: SOLVAY</p> <p>Optimistic case: 2018 LED market share = 38%, 2020 LED market share = 58%</p> <p>Pessimistic case: 2018 LED market share = 38%, 2020 LED market share = 38%</p> <p><small>This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation. © BRGM, 2019 70</small></p>																																									
<h3>4. Critical about criticality</h3> <p>Phosphors containing Eu and Tb are now a very small share of the total market, which has much reduced their criticality</p> <p>Source: SOLVAY</p> <p><small>This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation. © BRGM, 2019 71</small></p>																																									
<h3>5. Conclusions</h3> <ul style="list-style-type: none"> Restrictions to global supply of MRMs are more related to <u>access</u> to MRMs than to geological availability Access is limited primarily by economic, geopolitical, environmental and social factors Criticality assessments attempt to address the risk of supply disruption and economic/social damage through a multifactor ranking approach These methods are screening tools. Attempts to be « precisely quantitative » are limited by the diversity and complexity of factors Different methods deliver different results: there is no « correct » method; there is only adequacy of methods with specific user needs Therefore values can only be compared for a given methodology and in a relative sense <p><small>This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation. © BRGM, 2019 72</small></p>																																									
<h3>References for further reading</h3> <ul style="list-style-type: none"> ✓ Biagini, G. A., et al., 2017. EU methodology for critical raw material assessment : Policy needs and proposed solutions for incremental improvements. <i>Resources Policy</i>, 53, 12-19. ✓ Busje, B., Sievers, H., Tercero Espinoza, L., 2012. Limits to the critical raw materials approach. <i>Proceedings of the Institution of Civil Engineers - Waste and Resource Management</i>, 165(4), 201-208. ✓ EC, 2017. Study on the review of the list of Critical Raw Materials. Final Report. European Commission. ✓ Frenzel et al., 2017. Raw material 'criticality' – sense or nonsense? <i>Journal of Physics, D: Applied Physics</i>, 50. ✓ Graedel, T. E. et al., 2012. Methodology of metal criticality determination. <i>Environmental Science & Technology</i>, 46, 1063-1070. ✓ Graedel, T. E. & Reck, B. K., 2016. Six years of criticality assessments. What have we learned so far? <i>Journal of Industrial Ecology</i>, 20(4), 692-699. ✓ NRC, 2008. <i>Minerals, Critical minerals, and the U.S. Economy. Report of National Research Council.</i> Washington, DC: The National Academies Press. <p><small>This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation. © BRGM, 2019 73</small></p>	<p>References in bold could be read in priority.</p>																																								

3. Exercises

 <p>CRITICALITY ASSESSMENTS HANDS ON EXERCISES</p> <p>DOMINIQUE GUYONNET BRGM</p>  <p><small>This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation</small></p>	
<p>Objectives</p> <ul style="list-style-type: none"> • Calculate factors influencing criticality • Download information regarding criticality from the web • Gain insight into possibilities and limitations <p><small>This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation</small></p> <p>© BRGM, 2019 2</p>	
<p>1. Factor influencing "Supply Risk"</p> <p>Production Concentration</p> <ul style="list-style-type: none"> • Indicator of production concentration: Herfindahl-Hirschmann Index: $HHI = \sum_{i=1}^n s_i^2$ <p>where s_i is country « i »'s share in world production and « n » is the number of country's producing the raw material</p> <ul style="list-style-type: none"> ✓ If shares used as percentage, HHI (HHI_p) varies between 1/n (equal shares between n countries) and 1 (total concentration in one country) ✓ If shares used as percentage x 100, HHI (HHI_p) varies between 10 000/n (equal shares between n countries) and 10 000 (total concentration in one country) <p><small>This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation</small></p> <p>© BRGM, 2019 3</p>	
<p>1. Factor influencing "Supply Risk"</p> <p>Ranking (used in finance): </p> <ul style="list-style-type: none"> ✓ HHI < 0.01 (or 100): Highly competitive market (very well distributed production) ✓ 0.01 (or 100) < HHI < 0.15 (or 1 500): Unconcentrated production ✓ 0.15 (or 1 500) < HHI < 0.25 (or 2 500): Moderate concentration ✓ HHI > 0.25 (or 2 500): High concentration <p>Proposal:</p> <ul style="list-style-type: none"> ✓ HHI > 0.5 (or 5 000): Very high concentration (monopoly) <p><small>This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation</small></p> <p>© BRGM, 2019 4</p>	
<p>1. Factor influencing "Supply Risk"</p> <p>Exercise</p> <ul style="list-style-type: none"> • Calculate the Herfindahl-Hirschmann index for: <ul style="list-style-type: none"> ✓ Nickel ✓ Tungsten ✓ Lithium ✓ Cobalt • Use either percentage (HHI_p) or percentage x 100 (HHI_p) in calculation • Use 2018 data from the USGS. In Google search, e.g.: usgs cobalt <p><small>This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation</small></p> <p>© BRGM, 2019 5</p>	<p>This exercise is of interest for data mining: the students search the internet to obtain the data and then apply the formula</p>




1. Factor influencing "Supply Risk"


Results

• Nickel


	Mine production		
	2017	2018	
United States	22 700	18 000	n = 14 1/n = 0.071 HHI _n = 0.136 10 000/n = 714 HHI _n = 1358
Australia	178 000	170 000	
Canada	214 000	180 000	
China	133 000	115 000	
Colombia	45 000	43 000	
Cuba	52 800	53 000	
France	34 800	46 000	
Guatemala	53 700	48 000	
Indonesia	348 000	360 000	
Madagascar	41 700	39 000	
Mali (Guinean*)	11 000	20 000	
Philippines	348 000	340 000	
Russia	214 000	210 000	
South Africa	48 400	44 000	
Other countries	168 000	168 000	
World total (rounded)	2 160 000	2 300 000	



Unconcentrated production



Very high concentration




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1. Factor influencing "Supply Risk"

• Tungsten


	Mine production		
	2017	2018	
United States	975	980	n = 10 1/n = 0.1 HHI _n = 0.679 10 000/n = 1000 HHI _n = 6 792
Brazil	894	1 200	
China	67 000	67 000	
Portugal	724	730	
Russia	2 090	2 100	
Rwanda	320	830	
Spain	584	790	
United Kingdom	1 090	600	
Vietnam	6 000	6 000	
Other countries	1 300	1 400	
World total (rounded)	82 100	82 000	



Very high concentration



Very high concentration




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1. Factor influencing "Supply Risk"

• Lithium


	Mine production		
	2017	2018	
United States	94	91	n = 9 1/n = 0.11 HHI _n = 0.365 10 000/n = 1111 HHI _n = 3 652
Argentina	5 700	6 200	
Australia	40 000	51 000	
Brazil	200	600	
Chile	14 200	16 000	
China	6 800	8 000	
Portugal	900	800	
Namibia	—	500	
Zimbabwe	300	1 600	
World total (rounded)	68 000	68 000	



High concentration



High concentration




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1. Factor influencing "Supply Risk"

• Cobalt


	Mine production		
	2017	2018	
United States	640	500	n = 13 1/n = 0.077 HHI _n = 0.45 10 000/n = 769 HHI _n = 4 477
Australia	9 000	4 700	
Canada	3 870	3 800	
China	3 100	3 100	
Congo (Kinshasa)	73 000	80 000	
Cuba	5 000	4 800	
Madagascar	3 500	3 500	
Morocco	2 200	2 200	
Papua New Guinea	3 310	3 200	
Philippines	4 600	4 600	
Russia	5 900	5 900	
South Africa	2 300	2 200	
Other countries	7 800	7 800	
World total (rounded)	120 000	140 000	



High (very high) concentration




High (very high) concentration



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1. Factor influencing "Supply Risk"



From HHI alone:
Supply Risk Ni < Li < Co < W

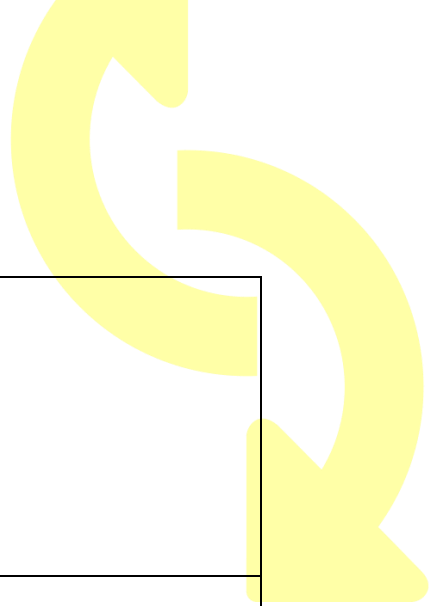
The students can see that based on the Herfindahl-Hirschman index, they obtain the same ranking of supply risk as in the EC 2017 Report on critical materials



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2. Economic Importance

$$EI = \frac{10}{Q_{max}} \sum_s A_s Q_s SI_{EI}$$

Where:

- A_s = share of demand for raw material in application "s" relative to total demand for raw material
- Q_s = Gross Value Added (GVA) of 2-digit NACE sector allocated to application "s"
- Q_{max} = Largest GVA of all 2-digit NACE sectors in list (next slide)
- $SI_{(EI)}$ = Substitutability Index associated with Economic Importance of raw material



2. Economic Importance

- The 2-digit NACE sectors

NACE : Nomenclature of Economic activities in the EC

- GVA (Gross Value Added) is a measure of the NACE sector's contribution to the EU economy
- Largest GVA (Q_{max}) = 227 000 M€ (D35 - Electricity, gas, steam and air conditioning supply)



2. Economic Importance

Exercise

- To which 2-digit NACE sector would you allocate the following two Sc applications:
 - SOFC: ?
 - Al-Sc alloys: ?
- Assume the following relative proportions of Sc-demand for these two applications:
 - SOFC: 90%
 - Al-Sc alloys: 10%
- Obtain Gross Value Added (GVA) for allocated NACE sectors from: http://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2

Note: use 2013 data (for compatibility with EC 2017 CRM report). Values are in Million €. Largest GVA (Q_{max}) = 227,309 M€

- Calculate EI assuming a Substitution Index (SI_{EI}) = 0.91 (Note: $SI = 1$ means no substitution)
- Compare result to EI for Sc in the EC 2017 CRM report

Here the students are again going to look for data on the internet and they will be able to calculate the same values of Economic Importance as those of the EC 2017 report on critical materials

2. Economic Importance

SOFC: NACE sector C27 (Manufacture of electrical equipment)

Scandium alloys: NACE sector C25 (Manufacture of fabricated metal products, except machinery and equipment)

These are screenshots of the pages with the required information

2. Economic Importance

Exercise (continued)

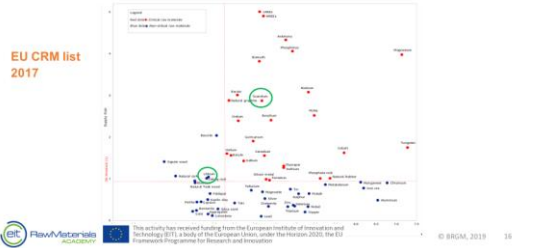

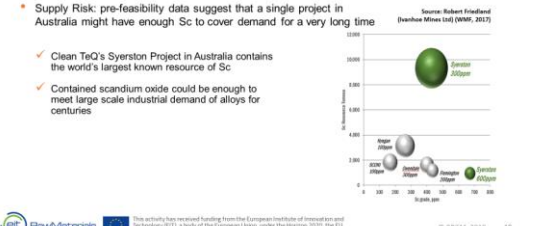
- Could do the same for Lithium, assuming the following applications and NACE allocations:

Application	Share	Large NACE sector	Share (Value in M€)
Other electronics	6.8%	C25	20,146
Other electronic products	6.2%	C26	19,148
Transportation	6.8%	C28	20,800
Machinery	5.8%	C29	17,788
Pharmaceutical products	4.2%	C24	12,840
Food and beverages production	4.2%	C15	12,840
Metals and metal products, except machinery and equipment	1.2%	C25	3,656
Products made of aluminium alloys	0.2%	C25	615

- And $SI_{EI} = 0.9$ (obtain EI = 2,4)
- Compare to EU CRM 2017 report

Any comments about the methodology?... 😊

Can do if time allows

<p>2. Economic Importance</p>  <p>EU CRM list 2017</p> <p>© BRGM, 2019 16</p>	<p>This graph highlights how Scandium scores higher in Economic Importance than Lithium. With the criticality thresholds selected by the Commission, Scandium appears to be critical while Lithium does not (which makes no sense at all...).</p>
<p>2. Economic Importance</p>  <p>EC, 2017</p> <p>© BRGM, 2019 17</p>	<p>The same with the precise scores for economic importance</p>
<p>2. Economic Importance</p> <ul style="list-style-type: none"> Why does Sc obtain such a high score in the EU methodology? Because the method takes the entire GVA of the allocated NACE sector Although SOFCs and Al-Sc alloys only represent a minute fraction of the GVAs of sectors resp. C27 and C25 <p>Seems to be missing in this methodology: a factor to account for the relative contribution of application « s » to the GVA of the 2-digit NACE sector allocated to the application...</p> <p>© BRGM, 2019 18</p>	<p>The explanation. For inexperienced group it may be difficult to pinpoint this major flaw in the methodology, so would have to be guided.</p>
<p>2. Economic Importance</p> <ul style="list-style-type: none"> Supply Risk: pre-feasibility data suggest that a single project in Australia might have enough Sc to cover demand for a very long time Clean TeQ's Systerion Project in Australia contains the world's largest known resource of Sc Contained scandium oxide could be enough to meet large scale industrial demand of alloys for centuries  <p>© BRGM, 2019 19</p>	<p>Puts the exercise in the perspective of real world exploration on Scandium. Indicated resources are abundant and criticality should not be a problem. Could also talk about Scandium in red muds from Aluminium industry</p>



4. Assessment Questions

Since the middle of the 20th century, world consumption of most mineral raw materials is:

- Answer 1: Rapidly increasing (correct)
- Answer 2: Rapidly decreasing
- Answer 3: Stabilizing
- Answer 4: Fluctuating

The following factor has the least real influence on criticality:

- Answer 1: The estimated reserve base (correct)
- Answer 2: Metal substitutability
- Answer 3: Time scale of the analysis
- Answer 4: Distribution of global metal production

Historically, metal contents in mined ores tend to:

- Answer 1: Decrease (correct)
- Answer 2: Increase
- Answer 3: Stabilize
- Answer 4: Fluctuate

Tungsten is critical because it is:

- Answer 1: Essential in certain industries due to its hardness (correct)
- Answer 2: A precious metal
- Answer 3: Very useful for air pollution control
- Answer 4: Used in permanent magnets for renewable energy

Tungsten is critical because it is:

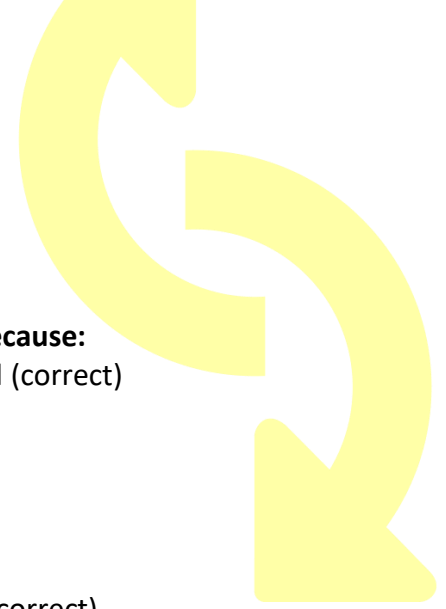
- Answer 1: Produced mainly by one country (China) (correct)
- Answer 2: Becoming too expensive
- Answer 3: Too difficult to mine
- Answer 4: Has a high toxicity

Criticality of Europium has changed rapidly because:

- Answer 1: It is much less in use since the advent of LED lamps (correct)
- Answer 2: New Europium deposits have been discovered
- Answer 3: It has become too expensive to use
- Answer 4: It is increasingly rare

Criticality estimates are:

- Answer 1: Relative estimates that depend on the method used (correct)
- Answer 2: Probabilistic risk assessments
- Answer 3: Precise and relatively well known for many metals
- Answer 4: About as useful as cooked bus tickets



Calculations of global metal depletion times are typically wrong because:

Answer 1: They assume that there is a fixed metal stock to be mined (correct)

Answer 2: They don't take into account recycling

Answer 3: They don't take into account substitution

Answer 4: They don't consider the entire value chain

The price of rare earths skyrocketed in 2011 because:

Answer 1: Of speculation following Chinese restrictions on exports (correct)

Answer 2: Rivalry between producing countries

Answer 3: The discovery of new high-tech applications for rare earths

Answer 4: A sudden depletion in global rare earth reserves

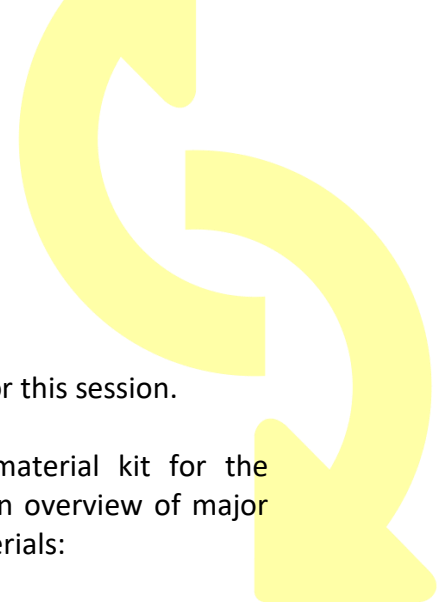
Criticality is usually a 2-dimensional matrix considering:

Answer 1: Economic importance and supply risk (correct)

Answer 2: Supply risk and metal price

Answer 3: Economic importance and geological availability

Answer 4: Metal price and recycling potential



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7. Disclaimer

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