Teaching Resources on the Sustainable Management of Critical Raw Materials

Trainer's Manual for
Critical Materials for Emerging Technologies

March 2020

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

Table of Contents

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

SusCritMat

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.

The collection of training manuals presents the key messages related with the sustainable management of critical raw materials in three major sections:

- Introduction to criticality
- Analysis of criticality
- Solutions for sustainable management

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 SusCritMat project is to qualify lecturers to teach the topics themselves. Therefore, the teaching resources do not only provide an introduction and improved insight into selected thematic issues, but 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.

eit RawMaterials ACADEMY

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

1.1 Training Materials List

The *SusCritMat project* developed the following teaching materials:

Basics
Critical Materials 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

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

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: 30 minutes
- Live quiz: 5 minutes
- Discussion on quiz results: 10 minutes

1.3 Key Messages

This training module introduces the role of critical metals for emerging technologies, a complex and dynamic field with a lot of uncertainties, but a crucial role for the future. The module consists of a presentation giving an overview of the topic

This module introduces first the notion of criticality. Along with module 3, "Criticality", it can therefore also be used for students without any prior knowledge about the topic. It is then shown that most of the known elements in the periodic table are relatively scarce. The number of different materials and the total mass used has steadily been increasing along with technological progress, economic and population growth, but there is only a limited amount of resources and some materials are very scarce in comparison to others. However, *the absolute limitation is not the most relevant issue in criticality, but merely the increasing effort needed to gather some raw materials*, e.g. because of declining ore grades. This should make students understand why we need criticality to take into account the implications of a material's scarcity for our economy and society. To illustrate the complexity of this issue, the examples of a mobile phone, wind power and electric vehicles are used. These key technologies for the future and a green energy transition require very specific elements like cobalt, neodymium, nickel etc. Thus, the availability of these technologies is directly related to the availability of these materials.

Supply insecurities are also influenced by geopolitical issues, as many materials are extracted in only a few countries, which makes their supply subject to political influences by those countries and often also coincidental with human rights abuses and environmental pollution. Many materials are only mined in combination with other elements or are a by-product of their extraction, which links the supply risks of those materials together. *Increasing mineral scarcity could be solved by a circular approach to materials*, but their dissipation into tiny amounts in the final products or into the environment through wear and tear or other processes makes their recovery often unprofitable or physically impossible today. Therefore, *efforts have to be made to lay the foundations for making critical raw materials more* *circular*. One important step is to look at a product over its full life-cycle from mining and product design to end of life.

1.4 Learning Objectives

After following this course, the learner should be able to:

- Define criticality;
- Explain why materials' criticality can pose problems for our economy, society, and a more sustainable future;
- Understand that different devices require different, sometimes very scarcely available materials;
- Explain the effect of dissipation;
- Explain the idea of a circular economy;
- Explain which circular economy measures can help reduce criticality.

1.5 Additional Reading

Angerer, G., Marscheider-Weidemann, F., Lüllmann, A., Scharp, M., Handke, V., Marwede, M., 2009. Raw Materials for Emerging Technologies. pp. 1–15. https://doi.org/10.1016/j.resourpol.2013.06.003.

Tercero, L., Schrijvers, D., Chen, W., Dewulf, J., Eggert, R., Goddin, J., Habib, K., Hagelüken, C., Hurd, A. J., Kleijn, R., Ku, A., Lee, M.-H., Nansai, K., Nuss, P., Peck, D., Petavratzi, E., Sonnemann, G., van der Voet, E., Wäger, P., Young, S. B., Hool, A., 2020. Greater circularity leads to lower criticality, and other links between criticality and the circular economy. Resources, Conservation and Recycling.

Ashby, M.F., 2016. Materials and Sustainable Development. Butterworth-Heinemann Ltd. https://doi.org/10.1016/C2014-0-01670-X.

Blengini, G.A., Blagoeva, D., Dewulf, J., Others, A., 2017a. Assessment of the Methodology for Establishing the EU List of Critical Raw Materials - Background Report. https://doi.org/10.2760/73303.

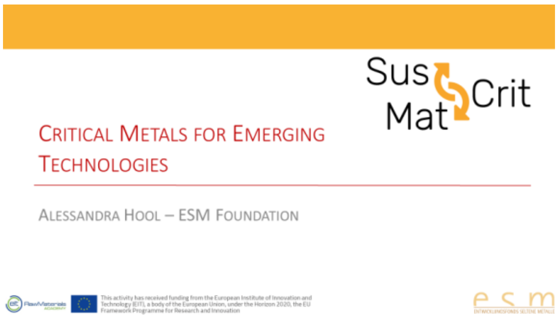
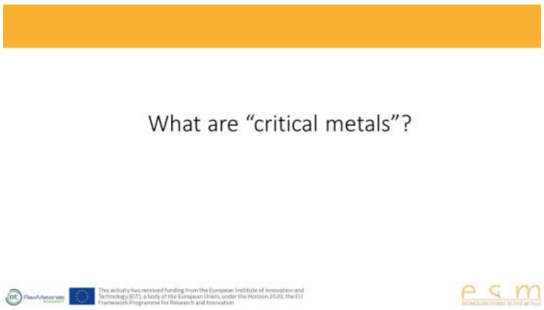
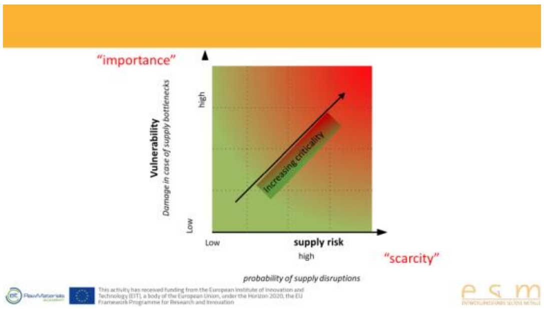
Buchert, M., Schüler, D., Bleher, D., 2009. Critical Metals for Future Sustainable Technologies and Their Recycling Potential. UNEP.

Graedel, T.E., Nuss, P., 2014. Employing considerations of criticality in product design. JOM 66, 2360–2366. https://doi.org/10.1007/s11837-014-1188-4.

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

2. Slides and Notes

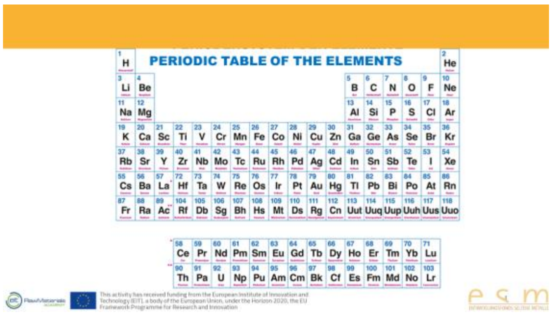
Slides are supplied in ppt format with annotations.

<table>
<tr>
<td>
</td>
<td></td>
</tr>
<tr>
<td>
</td>
<td></td>
</tr>
<tr>
<td>
</td>
<td>The «criticality» of a metal is not a physical property like ist melting point. Instead, it is a notion used to summarize in one value the attention that should be paid to one metal or other element in order secure its supply. This necessary attention depends both on the importance of a certain material (for whatever country, territory or company in question) and its availabity. All criticality assessment methods combine these two factors (importance and scarcity).

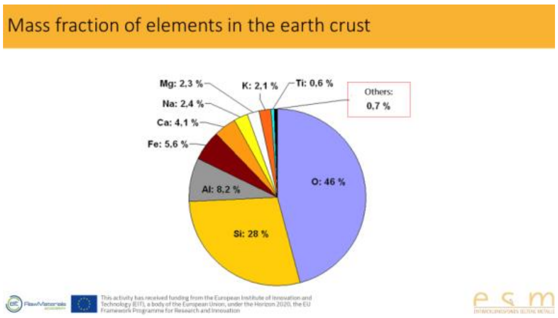
Both factors each bundle numerous other factors, such as the degree of concentration of the available reserves, substitution potential, possibility to recycle, and so on.

In this module, we are going to look at a few key issues involving criticality.</td>
</tr>
</table>

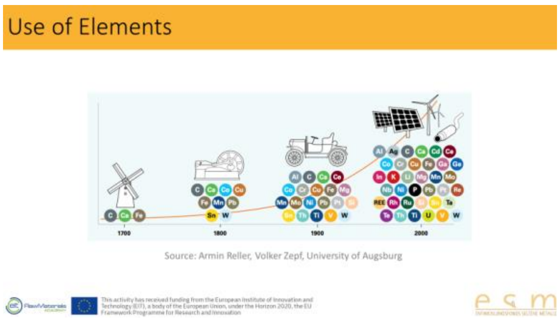
This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation



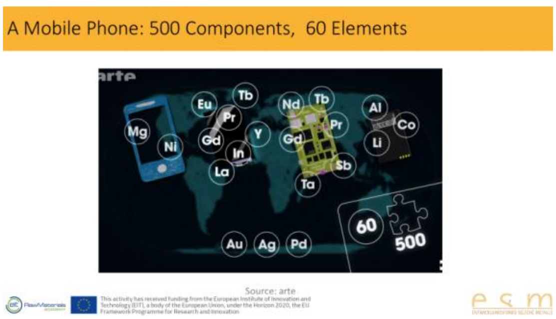
- 92 natural elements
- Everything we know is made up of these elements!
- We need to cope with what we have



- Unequally distributed
- Nine elements make up more than 99%
- Three quarters consist of oxygen and silicium, air and sand.
- All the other elements make up less than 1%.

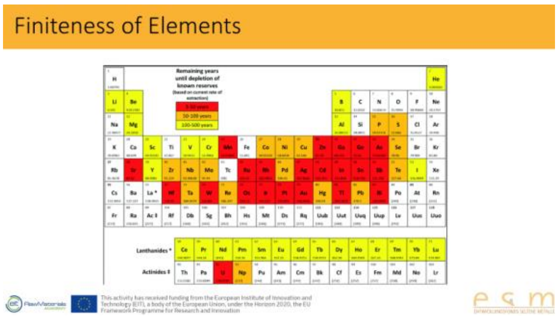


- For thousands of years, we used only stone, wood and iron for our technology.
- With industrialisation around 1800 (in Western Europe), example Wolfram
- More complex machines like cars with more complicated parts
- Today, there is almost no element left which is not used in some industrial application

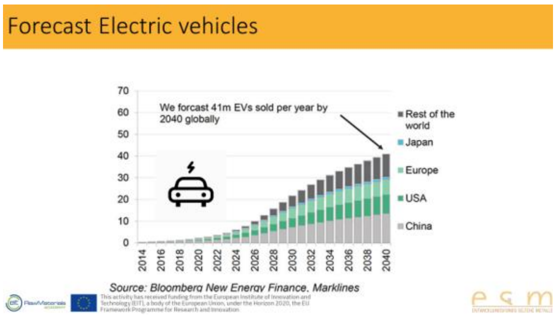


- A single mobile phone consists of 500 components
- 60 different elements <- two thirds of the entire periodic table
- Known elements like silver and gold
- Less known elements like cobalt or tantalum

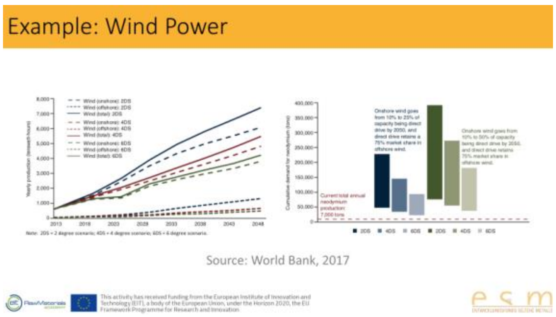
This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation



- Availability
- E.e. aluminium is very common, we will have sufficient amounts of it for several hundreds of years. Silver and gold, however, are considered critical elements.
- Example of Indium and Germanium: very scarce
- Caution with assessments is required
- When demand for an element is especially high, the efforts to extract it will also increase
- Difference between resources and reserves
- CAVEAT: there are natural boundaries! If I extract a metal to generate electrical current, the extraction of the metal must not be more energy-intense than the electrical current I can generate with it.



- Electric cars require, inter alia, large amounts of Nickel and Cobalt.
- The latter is considered highly critical due to its high concentration (world reserves are almost entirely in the DRC)

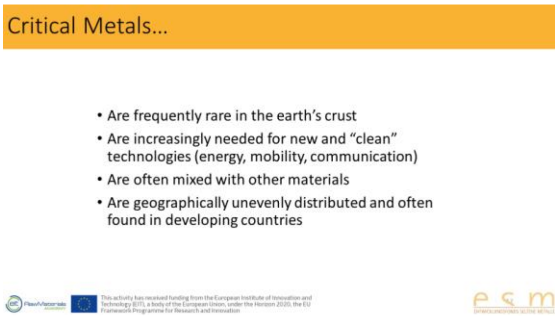


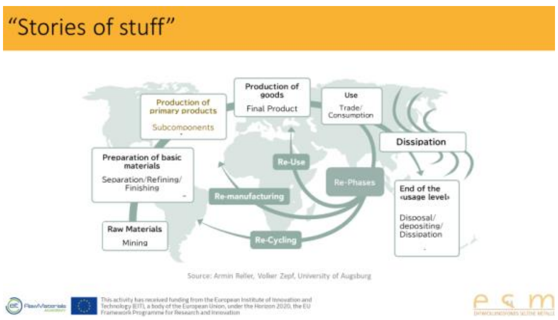
- Climate scenarios
- Consumption of neodymium – a rare earth metal

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

Where do the metals come from?

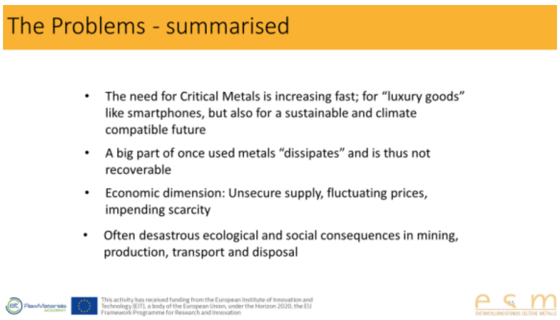
- As you can see in this image, most metals are not sourced in Europe or even its immediate vicinity
- North America and Japan have some metal resources; otherwise, the countries most rich in resources are mostly developing countries
- We also see the Congo (DRC) here, an extremely poor African country. Tantalum, amongst others, is extracted here.
- China also deserves mentioning. With respect to many raw materials, we are dependent on China and its export policies. China introduced temporary export limits on certain elements which skyrocketed the price for these materials. In the current „trade war" between the USA and China, one of the issues are „rare earths", more than 95% of which are extracted in China.



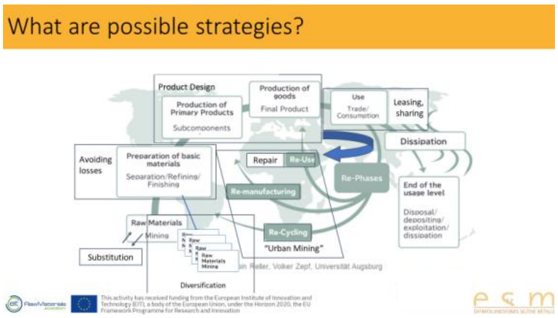


- The „circle" of an item from the beginning (mining) to the end, its end of life.
- Resources are processed into basic materials, from which primary products are made (e.g. a smartphone display); these primary products are combined with others to create the final product, whose raw materials at the end the

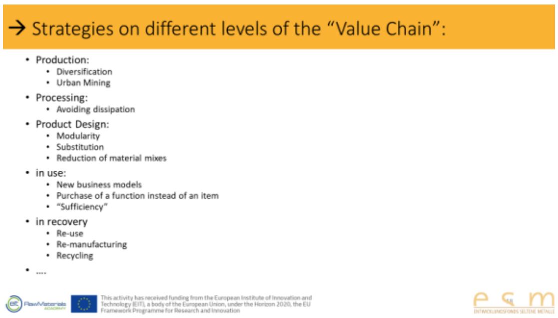
This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

	product‘s life cycle are either dissipated into the environment or reused. • One of the major problems contributing to materials‘ criticality is that a materials‘s inclusion into certain products decreases the concentration of this material on a global level; materials are heavily concentrated in mines first but then are dissipated into billions of e.g. smartphones. The concentration of certain materials in the end products is often so small that it is not economically feasible to recycle them.
	• Besides the fact that elements are not infinitely available, the extraction and production of critical elements has often disastrous social and ecological consequences. • 50-80% of electronic are deposed of in developing countries • Recycling is often not profitable, because new production is cheaper
	
	• Politics has recognised the problem; the EC stated five years ago already that society needs to aspire to a circular economy, which means that fewer elements are lost in consumption, and more retained in the value chain.

RawMaterials ACADEMY
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



- What happens to a smart phone which has been broken?
- You have it repaired, offer it to someone as a gift, sell it or donate it. In each of those cases, it is reused.
- You give it back to the manufacturer. If you are lucky and the manufacturer has a good recycling policy, he will disassemble the device.
- Into single components which are resused afterwards: „Re-manufacturing“
- Single metals which are used for new components: „Re-Cycling“



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

3. Assessment questions

The elements in the earth's crust:
Answer 1: are more or less evenly distributed over geographic regions
Answer 2: do have similar mass fractions
Answer 3: have similar chemical properties
Answer 4: none of the above (correct)

Extracting metals from mines tends to …
Answer 1: be more energy-intensive over time (correct)
Answer 2: be less energy-intensive over time (correct)
Answer 3: stabilize
Answer 4: fluctuate

The recycling rates of critical metals are low because …
Answer 1: it is often more expensive to mine a critical metal than to recycle it
Answer 2: critical metals often make only a small share of a product or compound
Answer 3: products are not designed in a way that enables recycling
Answer 4: all of the above (correct)

"Dissipation" means …
Answer 1: waste in material mining and processing
Answer 2: that a material is not brought to recycling
Answer 2: that a material is lost for human use (correct)
Answer 3: that a material is not used efficiently

Our use of materials …
Answer 1: … has substantially increased over the last few hundred years and is continuing to increase globally (correct)
Answer 2: … has substantially increased over the last few hundred years but is now about to decrease
Answer 3: … has substantially increased over the last few hundred years and is today still increasing, but only in developing and emerging economies
Answer 4: None of the above.

eit RawMaterials ACADEMY
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

SusCritMat

4. Acknowledgements and Authors

This teaching material was prepared by Alessandra Hool from ESM Foundation.

The following authors have contributed to prepare the complete teaching material kit and intend to provide an overview of major topics surrounding the sustainable management of critical raw materials:

Ruud Balkenende, TU Delft

Stefano Cucurachi, Uni Leiden

Andrea Gassmann, Fraunhofer IWKS

James Goddin, Granta Design

Dominique Guyonnet, BRGM

Heinrich Hofmann, EPFL

Alessandra Hool, ESM Foundation
Amund Loevik, Empa

David Peck, TU Delft

Armin Reller, ESM Foundation

Antti Roine, Outotec

Dieuwertje Schrijvers, University of Bordeaux

Guido Sonnemann, University of Bordeaux

Layla van Ellen, TU Delft

Tatiana Vakhitova, Granta Design

Ester van der Voet, Uni Leiden

Patrick Wäger, Empa

Jan-Henk Welink, TU Delft

Steven Young, University of Waterloo

Besides, many others invested their time and expertise to discuss and review this teaching material.

5. Citation

Please cite the SusCritMat teaching material as follows when using them for your curriculum:

SusCritMat – Sustainable Management of Critical Raw Materials, funded by EIT RawMaterials, April 2017 – March 2020.

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

6. Disclaimer

The teaching materials within the SusCritMat project have been prepared with great care and experienced several revisions. Nevertheless, the consortium assumes no liability for the topicality, completeness and correctness of the content provided.

In case you have suggestions or other feedback how to improve the materials, we value your opinion: Please contact us via the project webpage https://suscritmat.eu/contact/.

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