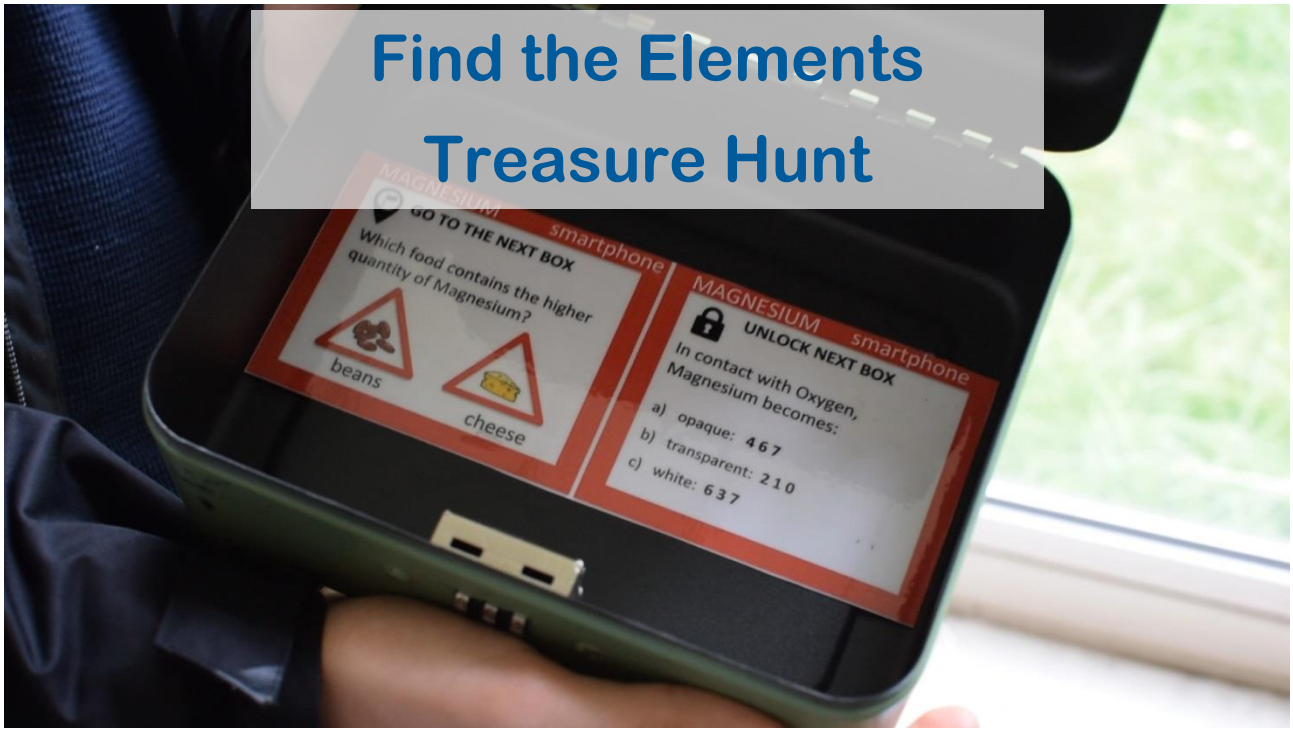
Teachers' Card

Find the Elements Treasure Hunt



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General Introduction

Find the Elements is and educational game meant to make players aware of the problems of critical raw materials, electronic waste revalorization, urban mining and circular economy. This is achieved by learning information about some important chemical elements, mainly critical ones, present in the most common electronic devices.

The activity works as a revisiting of the classic treasure hunt. Players, alone or in teams, follow a series of element-themed clues until they find the key to open the treasure chest at the start and win the game. Different, separate courses can be set up, so that more than one group of people can play at the same time. Find the Elements can be played indoors, outdoors or a combination of both. The outdoors version can be played using the "what3words" app to geolocalize the boxes.

The game can be played by all people age 10 and up; for groups of older students and adults, the questions can be adapted to be more challenging. If no obstacles are present on the path, the game can easily be played by people with physical disabilities too. There is no set number of people that can play the game at any given time, it only depends on the available spaces. No specific background knowledge is required.

The duration of the activity can vary depending on the complexity of the courses, but anything between 30 to 60 minutes is recommended.

Key words: Critical raw materials; Electronic devices; Critical metal recovery; WEEE; Circular economy

Extended Background Information

WASTE OF ELECTRICAL AND ELECTRONIC EQUIPMENT (WEEE)

Waste of Electrical and Electronic Equipment, or E-waste, consists in all the parts of End-of-Life technological devices which have been thrown away and contain materials that could be recycled.

They comprehend electrical instruments, like laundries, hair driers, fridges, etc., and electronic components, like computers, mobile phones, cameras, etc.; this means that WEEE is a big category of no more used products that must be adequately managed in order to reduce their World Wide impact.

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Although E-waste is increasing with years, this problem is still undervalued, causing relevant damages to the environment.

Just EU Community generates about 10 tons of WEEE per year and it is estimated that this number will reach about 12 tons per year in 2020. Italy produces now 4 kg per person every year, but in 2020 this value could be at least three times larger.

Nowadays, distributors have the duty to collect all WEEE from private customers, but statistics show that quantities do not reach more than the 7% per year. Thus, both suppliers and consumers must be made mainly responsible for this problem.

It would be necessary to give more attention in how to collect and how to drain them off. Some gathering places have been already placed around residential areas, in addition to the ones provided by the commercial exercises.

The faster solution to clean the scraps out would be the use of an incineration process, but it is an old and less profitable operation, with the further necessity of dealing with NO_x and SO_2 emissions. Chemical agents and filters can control and limit the formation of these oxides, but their use means high costs and also a lack of economic benefits that could be obtained by recycling some of the components contained inside the scraps. It has been also estimated that 36 tons per year of mercury and 16 tons per year of cadmium are released from this process just in Europe.

If these components could be treated more adequately, there would be a lot of advantages, not just because of a reduced environmental impact, but also economically: there would be fewer costs due the reduced extraction of raw materials from mines.

POSSIBLE TREATMENTS

Some convenient solutions have been found to face the problem of getting rid of WEEE.

Firstly, scraps could be reused, sold or given away for free, in order to reduce costs more efficiently than in any other kind of treatments, valorising them with no direct interventions. Nevertheless, the aim of assigning a product a second life-cycle cannot be adopted for the whole E-waste: it is necessary to find other cheap and optimal techniques, clearly different from the old incineration process which is expensive and not environmentally friendly.

Remanufacturing WEEE could be a further option: it means that some parts could be repaired and used again instead of being eliminated, resulting in a significant energy saving. Even this solution cannot be applied for every E-waste.

Thus, the so-called "urban mining" has been developed, with the proposal of collecting, transporting, recycling and recovering WEEE to get some pure elements from scraps and use them as raw materials.

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CHEMICAL CONTENTS

It has been shown that "urban mining" is fundamental because it avoids the stack of WEEE and provides a good sustainability, decreasing the negative effects produced on the environment.

This process also permits to recover precious and rare metals that could be sold like regenerated raw materials. Actually, WEEE contains not just common elements like lead, copper or iron, but also precious metals, like gold or platinum, employed inside electronic equipment because of their stability and good conductivity.

Table 1.1 shows the percentages of some elements that could be found inside different electronic samples.

Table 1 - Principal composition of some scraps

Electronic waste	Fe %	Cu %	Al %	Pb %	Ni %	Ag %	Au %	Pd %
TV board scrap	4	39	13	2	5	6	25	6
PC board scrap	0	16	1	1	3	4	62	13
Mobile phone scrap	0	8	0	0	0	5	67	19
Portable audio scrap	3	78	1	0	0	3	12	2
DVD player scrap	17	35	4	1	1	4	33	4
Calculator scrap	1	12	6	0	8	6	64	3
Printed circuit board scrap	1	19	4	1	6	3	66	-

Even rare earths can be found, their relevance is increasing because they are more and more used into new technological applications.

RARE EARTHS

Rare Earths consist in a group of elements (15 lanthanides plus yttrium and scandium) whose name takes origin by the fact that they were first isolated in 18th and 19th Centuries starting from minerals that were supposed to be uncommon. Just in the 20th Century all Rare Earths were identified and separated; the difficulty in treating them as pure components is due just to their high reactivity.

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Despite their name, REEs are quite common (except for promethium which does not have long-lived stable forms) and all of them can be found in higher quantities with respect to other metals like, for example, silver or mercury.

Actually, Rare Earths are lithophile elements: they tend to form silicates or oxides that are mostly concentrated into the Earth's crust as natural deposits. These configurations are quite stable because all the lanthanides are trivalent, except for Cerium and Europium in some environments. Moreover, they have similar ionic radii, so they could liberally exchange their positions each other into a reticulate.

REEs are usually divided into two main groups:

- LREEs (Light Rare Earth Elements) that are: Lanthanum, Cerium, Praseodymium, Neodymium, Samarium and Europium.

- HREEs (Heavy Rare Earth Elements) that are: Gadolinium, Terbium, Dysprosium, Holmium, Erbium, Thulium, Ytterbium, Lutetium and Yttrium, which is the lighter RE but has chemical and physical qualities nearer to the heavy components.

There are not substantial differences between the two groups because, as anticipated before, lanthanides have similar properties. Some little chemical and physical changes are caused by small variations of their ionic radii.

ECONOMIC ASPECTS

Rare Earths are not distributed equally onto the earth crust, so the real problem is not their global concentration (10-500 ppm by weight), but their relative one. The best known mines are located in California (Mountain Pass), some in Australia and Russia but, above all, in China, with more than 55 million tons (Massari and Ruberti, 2013) of REEs reserves that corresponds to more than 83% of the world production, like shown in Figure 1.

In June 2010, the European Commission classified these elements like critical, by the fact that their natural deposits are concentrated just in some regions which must be carefully evaluated from both political and economic points of view.

Figure 2 shows three different groups which distinguish Rare Earths basing on their criticism.

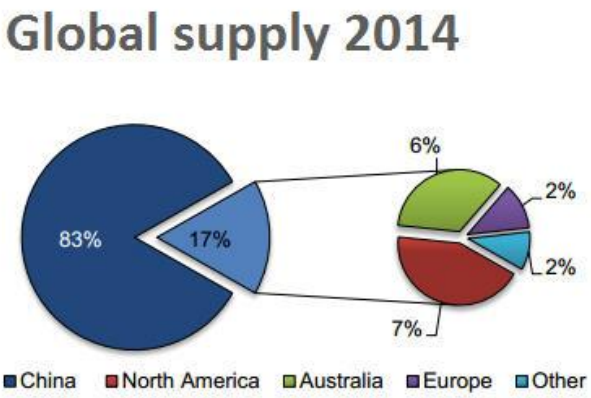

Figure 1 – REEs Global supply

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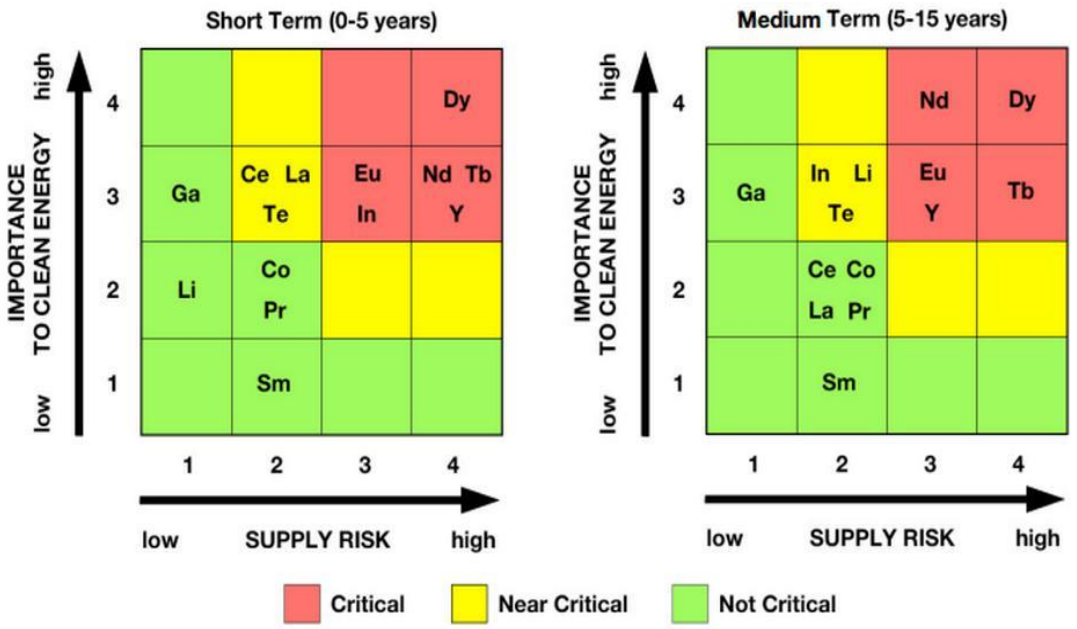

Figure 2 - Supply risk for REEs

Moreover, Rare Earths are used quite frequently nowadays, because of their recent applications inside highly technological products and they cannot be replaced easily, so costs increase because of the lack of potential substitutes.

Neodymium, for example, is mostly implied to build permanent magnets and Europium and Yttrium are used for colour televisions while further applications are listed in Figure 3.

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Figure 3 - Possible uses of REEs

Thus, the REEs economics is continually changing due to both the global demand, which is controlled by the development of new technologies, and the marketing choices of the countries that own this kind of mines.

These are the reasons why prices are constantly fluctuating: UE launched the "European Raw Materials Initiative" to invite promoting and developing a recycling process for End-of-Life products, among other proposals.

Another essential aspect is that China is emerging not just like one of the most important extractor of Rare Earths but is also one of the principal consumers, together with Japan, USA and a little percentage in Korea and Europe, as shown in Figure 4. China results in having a fundamental role for what concerns the definition of the prices of each Rare Earth: it owns the major part of the World Wide mines and its rapid industrialization, together with its rising economics, leads to an intensified global competition and a consequent increasing of the raw materials costs. Their economical variation is individual and it is due to a balance problem: the demand of a singular element is not equally balanced with its supply. This means that some products are extracted from minerals containing even other REs that could be produced in excessive quantities with respect to the real industrial request and needs.

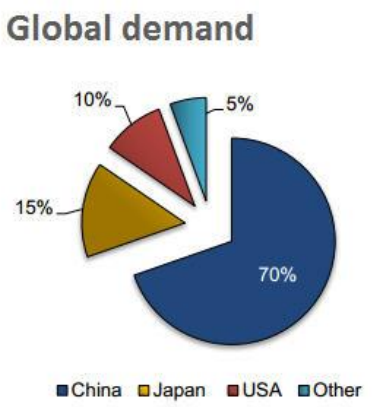

Figure 4 - Global demand for REEs

In conclusion, recycling WEEEs permits to face firstly some environmental problems, concerning high consumption of water and large energy wasting, which are necessary for the extraction process. Recovery REEs can be also seen as a social improvement, because it could bring new job opportunities and reduces damages to the men's health.

EXTRACTION TECHNOLOGIES

Lots of processes were previously concentrated in finding an optimal solution just for the recovery of precious metals. Recently, even the recycle of rare earths have been considered, especially after having considered the economic aspects discussed above.

Figure 5 shows the main steps to recover materials from WEEEs: there is a first disassembling process, followed by the upgrading one, to conclude with the refining phase. This last operation can be done using three different techniques: via pyrometallurgical, biometallurgical or hydrometallurgical procedures.

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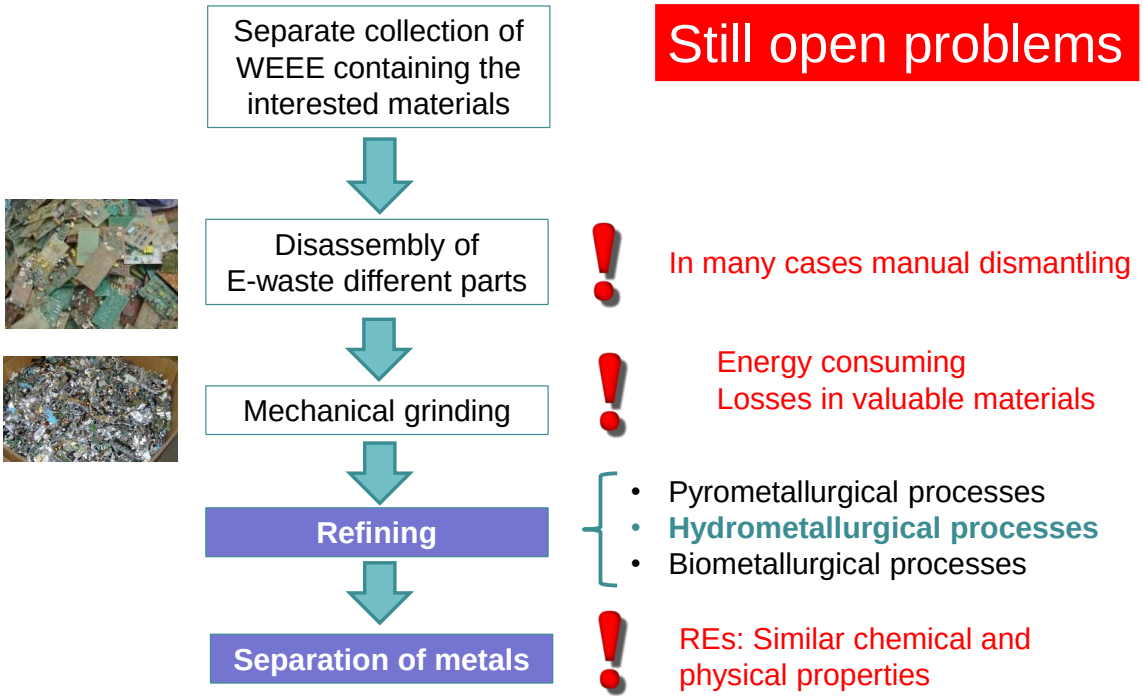

Figure 5 – Metals recovery from WEEE

The pyrometallurgical method is one of the oldest technique and, although its inefficiency, it is briefly reported. This process includes some steps, like incinerating, sintering and melting the scraps without controlling the unwanted production of dioxins and other toxic components. Another relevant problem is the low yield: products (in particular precious metals and not REs) can be obtained just partially and at the end of the whole operation. Furthermore, pyrometallurgy is strongly energy consuming.

Biometallurgy exploits bacteria, with the function of catalysts, which can actively or passively interact with the scraps to decompose them. In particular, biosorption consists in a selective or non-selective procedure which uses algae, fungi or bacteria that optimally absorb metals to complete their intracellular functions. Its greatest limit is that there are a lot of difficulties in separating the small particles that have been obtained at the end of the process from the rest of the final solution.

The hydrometallurgical method results in being one of the most valuable choice because of its advantages: it can be easily controlled, requires just a leaching and a recovering process in smaller volumes with respect to the previous techniques. Even if it uses a large amount of chemicals and requires a conversion of scraps into liquid solutions and a reconversion into solid elements, this process is considered the best one.

A relevant focusing must be done on the separation of elements inside the leached solution: the recovery of precious metals is rather consolidated, while there are still some difficulties in managing Rare Earths, due to their similar physico-chemical properties.

Nevertheless, a lot of techniques have been investigated, with the result that this last step can be done through: chemical precipitation, fractional crystallization, ion exchange or solvent extraction.

The chemical precipitation is quite common, but permits just a partial separation of the elements in different subgroups, depending on the operative conditions.

The fractional crystallization is the oldest solution, but nowadays it is not used frequently because of a reduced pureness of the final products.

A high purity can be reached with an ion exchange, even if it is employed to obtain just little quantities, because it requires equipment with big volumes and the process is not continuous.

Thus, solvent extraction seems the best technique: a liquid and selective substance, with chelating properties, contacts the solution of the leached scraps. This operation is carried out in counter-current conditions and the solvent is partially recovered and reused. Some other liquids can be added to improve the efficiency of this step. The whole process is continuous and does not require big volumes, but even solvent extraction is characterized by some limitations. First, a liquid-liquid equilibrium must be found, in order to reach the higher productivities, but this is not always guaranteed. Moreover, the majority of the solvents are not cheap and neither environmentally friendly.

Therefore, a further technique has been developed: the solid-phase extraction, which avoids the use of hazardous liquids and the production of a big quantity of sewages.

SOLID-PHASE EXTRACTION

The solid-liquid extraction exploits the presence of solid elements that can adsorb and retain the products of interest. They are usually distributed inside columns, disks or tubes where the contact with the liquid phase occurs. Afterwards, solids are purified and the components are collected.

This method results the most efficient for what concerns REEs recovery: yields are higher than the ones obtained from other processes, costs are reduced, no hazardous solvents are employed and times are significantly reduced because extended surfaces are available for the adsorption.

Lots of solid matrices can be used for this purpose, the choice depends on the selectiveness of the process; it would be possible to use: nanotubes, membranes, resins, silica, clays or organoclays.

Nanotubes can be produced with carbon, which is a common resource, but is preferred just when the final targeted composition is not specific.

Titanium dioxide nanotubes have better features, like a higher superficial area than the carbon ones, good stability, low cost and an excellent resistance to corrosion. They can reach even the 95% of REEs recoveries for La, Ce, Eu, Gd, Lu and Yb.

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Membranes have been investigated just recently; they operate with a non-equilibrium mass transfer, where solutes move from low to high concentration sites. This solution is frequently coupled with a LLE, because liquids can favor the transport through the membrane.

Resins are quite efficient, for what concerns the separation process via chromatography, and selective. They are composed by porous polymers modified by the presence of appropriate solvents that make them to be selective for the elements of interest. Their surface area is particular extended, no phase separations are observed and a little quantity of organic solvents is used.

Silica is a good support because of its high thermal and mechanical resistance, but it needs to be modified with chelating agents in order to improve its selectivity.

Clays and active carbons, can be considered the best solid matrices because of their natural attitude in adsorbing REEs. Moreover, they are a low-cost material, have high mechanical resistance and can tolerate acid environments. These materials can also be modified to improve their capture capability.

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Key Competence European Framework

Literacy competence
S1. Ability to understand and interpret concepts, feelings, facts or opinions in oral and written form.
S2. Ability to express concepts, feelings, facts or opinion in written and oral form.
S3. Ability to interpret the world and relate to others.
S4. Ability to interact in an appropriate and creative way in any situation.
Multilingual competence
S5. Knowledge of vocabulary, grammar and language.
S7. Ability to use technical language accordingly to the field of work.
Mathematical competence and competence in science, technology and engineering
S1. Ability to use constructed thinking in order to solve a problem in every situation.
S4. Readiness to address new problems from new areas.
S5. Capacity for quantitative thinking.
S6. Ability to extract qualitative information from quantitative data.
Digital competence
S1. Critical use of information technology for work.
S2. Basic skills in ICT.
S4. Ability to use and handle technological tools and machines.
Personal, social and learning to learn competence
S1. Ability to pursue and persist in different kinds of learning.
Citizen competence
S1. Ability to effective interaction with other people.
S2. Ability to adapt to the changing situation, being flexible and work under pressure.
S3. Ability to work effectively and collaborate with other team members.
Cultural awareness and expression competence

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S1. Ability to turn idea into action.
S2. Creativity/innovation.
S3. Ability to plan and manage tasks.
S4. Independence, Motivation and Determination.

United Nations' Sustainable Development Goals

The Sustainable Development Goals are the blueprint to achieve a better and more sustainable future for all. They address the global challenges we face, including those related to poverty, inequality, climate change, environmental degradation, peace and justice.

	1 NO POVERTY, 2 ZERO HUNGER — Enable access to basic services		10 REDUCED INEQUALITIES — Equal access to global expertise
	3 GOOD HEALTH AND WELL-BEING — Safe medical devices	✓	11 SUSTAINABLE CITIES AND COMMUNITIES — Sustainable urbanization
✓	4 QUALITY EDUCATION — Access to education	✓	12 RESPONSIBLE CONSUMPTION AND PRODUCTION — Responsible consumption and production
	5 GENDER EQUALITY — Less hardship, more opportunities		13 CLIMATE ACTION — Strengthen resilience, reduce disaster impact
✓	6 CLEAN WATER AND SANITATION — Safe and affordable water		14 LIFE BELOW WATER — Reduce marine pollution
✓	7 AFFORDABLE AND CLEAN ENERGY — Energy – the golden thread		15 LIFE ON LAND — Sustainable use of terrestrial ecosystems
✓	8 DECENT WORK AND ECONOMIC GROWTH — Safety of workers and economic growth		16 PEACE, JUSTICE AND STRONG INSTITUTIONS — Promote peaceful and inclusive societies
✓	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE — Resilient infrastructure and sustainable industrialization	✓	17 PARTNERSHIPS FOR THE GOALS — Better access to technology and innovation

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Activity

Find the Elements is a treasure hunt game. Each player or group of players will follow a course along which they will find a series of hidden boxes, which contain multiple choice questions that, if answered correctly, will give them the correct path to follow to find the next box and the combination to open it.

Find the Elements can be played indoors, outdoors or a combination of both; the outdoors parts can be played using the "what3words" app to geolocalize the boxes, by giving the words corresponding to the location of the next box for the solution of the multiple choice questions

You can find all the detailed instructions on how to set up and organize the activity in the:

Module 1 for Teachers - Find the Elements

Learning Pathway

Step 1 – 60 minutes: The teacher holds a lesson to the class on the topics of Rare Earths, WEEE treatment, economics and extraction techniques, using the information contained in this document ("Extended Background Information") as a reference.

Step 2 - about 180 minutes: Students perform a research individually or in small groups connected to the topics of the toolkit.

Step 3 – 60 minutes: Presentation of the students' researches & debate in class.

Step 4 –variable: Setting up of the "Find the Elements" game for the students to play.

Description of Student's Cards

Student's Card 1 - In this document you will find a list of sample Informational Sheets to give to the players before they start the game. These Informational Sheets are related to the sample Devices, Elements and Questions provided in **Module 1 for Teachers**, so if you decide to create different ones you may need to modify the Informational Sheets too.

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Sources

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