From Urban Mining to Industrial Policy

The FutuRaM Project

A SPECIAL REPORT by EconomiaCircolare.com
L'informazione in circolo

In Collaboration with FutuRaM

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Introduction

by Raffaele Lupoli
Director of EconomiaCircolare.com

Critical raw materials are now one of the key nodes in the twin transitions — Europe's ecological and digital transitions. Batteries, electric vehicles, photovoltaic panels, wind turbines, electronic equipment, and high-tech infrastructure require indispensable materials, yet these are exposed to **supply risks**, geographic concentration of supply, and global industrial competition. This special report by EconomiaCircolare.com originates from the need to shift the perspective from traditional mines to "urban mines" — i.e., waste streams, end-of-life products, components and materials already circulating within the European economy — which can become a strategic source of secondary raw materials.

The European "**FutuRaM – Future Availability of Secondary Raw Materials"** project provides a fundamental knowledge base to understand this transformation. Funded under Horizon Europe, FutuRaM has developed a European knowledge base on the availability and recoverability of secondary raw materials, with a specific focus on critical raw materials, across the EU27+4 (European Union plus Iceland, Norway, Switzerland, and the United Kingdom). The project analyses **six major streams**: end-of-life batteries, waste electrical and electronic equipment (WEEE), end-of-life vehicles (ELV), extractive waste, slags and ashes, and construction and demolition waste, including decommissioned wind turbines. The goal is not only to estimate how much material is contained in these waste streams, but to understand where it is located, in which products and components, at which quality levels, what losses occur along collection and treatment, and which technical, economic, regulatory, and industrial conditions make recovery feasible.

> *"The future availability of critical raw materials will also depend on how effectively Europe can measure, collect, separate, and recover them — and above all, on how well a coordinated industrial strategy can be implemented across countries.*

This report illustrates how the project lays the groundwork for defining an **industrial policy infrastructure**. Its stock-and-flow models, composition analyses, 2050 scenarios, and the Urban Mine Platform enable the identification of material hotspots, estimate the theoretical availability of secondary raw materials, and support evidence-based public and industrial decision-making. From this perspective, recovery becomes a lever to **simultaneously reduce the overexploitation of natural resources and strategic dependencies**, retain value within European value chains, improve the quality of incoming waste streams at treatment facilities, and guide ecodesign, selective collection, treatment technologies, and investments.

The articles in this report follow this path, starting from the European context on critical raw materials and delving into the case of WEEE and missing supply chains, illustrating 2050 scenarios and the Italian situation. Through the lens of the FutuRaM project, EconomiaCircolare.com creates an ideal **bridge between research, industry, and policy**, showing that the future availability of critical raw materials will also depend on how effectively Europe can measure, collect, separate, and recover them — and above all, on how well a coordinated industrial strategy can be implemented across countries.

FutuRaM Project Partners: WEEE Forum, UNITAR, Erion WEEE, Empa, Universiteit Leiden, Technische Universität Berlin, Ludwig-Maximilians-Universität München, BRGM, Sociedade Portuguesa de Inovação, Chalmers Tekniska Hoegskola AB, University College London, VITO, Geološki Zavod Slovenije, Sveriges Geologiska Undersökning, Geological Survey of Finland, Bundesanstalt für Geowissenschaften und Rohstoffe, Boliden Mineral AB, ecosystem, Ecogenesys, WEEECycling, Lovisagruvan, University of Belgrade Faculty of Mining & Geology, Duncan Kushnir, RECHARGE, Stiftung GRS Batterien, European Metals Recycling, Mace, Otanmäki Mine Oy.

FutuRaM Project: Urban Mining at the Core of European Industrial Policy

Funded by Horizon funds, the FutuRaM project lays the foundations of the statistical infrastructure needed to enable recycling of Waste Electrical and Electronic Equipment (WEEE) to make a qualitative leap: from managing a problem to becoming a tool for industrial competitiveness and resilience.

By **Alessandro Coltré**

There is a point in European industrial policy where the green transition is no longer just **about clean technologies** but also **about data**. Knowing how many critical raw materials (CRMs) are already present in the European economy, where they are located, in which products, components, and waste streams, has become a prerequisite for **reducing dependence on external suppliers and building more resilient industrial value chains.**

This is the space where **FutuRaM** positions itself, as a **European project** funded by Horizon that outlines the future availability of secondary raw materials, with particular attention to **critical raw materials** (CRMs).

FutuRaM focuses on **six main waste streams**: end-of-life batteries, electrical and electronic equipment (WEEE), end-of-life vehicles (ELV), construction and demolition waste, slags and ashes, and mining residues. The project has developed **methodologies, reporting frameworks, and digital tools** (including the Urban Mine Platform) to model the flows and stocks of secondary materials and CRMs up to 2050, enabling the identification of material hotspots, the assessment of their recoverability, and the simulation of future availability and circularity scenarios. Among the **28 project partners** are universities, research institutes, industries, and sector associations from **11 countries**, collaborating closely with the European Commission and other key policy stakeholders.

Numbers, Industrial Policies, Resilience

If Europe wants to attempt greater independence from global supply chains, how much can it rely on raw materials already present in the form of goods within Europe? How much can it extract from what, in a suggestive metaphor, we call **"urban mines"**?

Batteries, WEEE, end-of-life vehicles, construction and demolition waste, decommissioned wind turbines, slags and ashes, mining residues: these are **no longer just environmental problems to manage, but potential secondary deposits**—to be measured, assessed, and made industrially accessible in order to become a pillar of continental supply and industrial competitiveness. Not by chance, the **Clean Industrial Deal** identifies the circular economy as a tool to "reduce excessive dependence on third-country raw material suppliers, which is essential to ensure a competitive and resilient market."

The Critical Raw Materials Act and the Role of Urban Mining

The process is political before being technical. The Critical Raw Materials Act (CRMA) set clear targets for 2030: at least **10% of the EU's annual consumption** of strategic raw materials to be covered **by domestic extraction**, at least **40% by processing capacity**, at least **25% by recycling**, and no more than 65% of the supply of a single CRM from one third country.

> *"FutuRaM adds an essential layer: the ability to distinguish between what is actually present in the waste, what is theoretically recoverable, and what is lost along the value chain.*

The European Commission then began translating this framework into an industrial pipeline, approving the first **Strategic Projects in 2025: 47 projects within the EU and, subsequently, 13 projects outside the EU**. (As an aside, it should be noted that European deregulation—particularly regarding corporate due diligence—could make some of these projects problematic or contradictory to the EU's ambitions for a just transition.)

In this context, it would be short-sighted (and harmful) to confine recycling to a matter of waste or environmental policy: it is—or at least should be—**fully part of European industrial policy** (the mentioned Clean Industrial Deal), supply security, and the autonomy and resilience of the industrial system. While the CRMA requires Member States to improve the collection and recycling of waste rich in critical raw materials, FutuRaM adds an essential layer: the ability to distinguish between what is actually present in the waste, what is theoretically recoverable, and what is lost along the value chain. Without this distinction, urban mines would remain a suggestive metaphor—one of the tools of green rhetoric—without providing a **tangible contribution to the resilience of European industry**.

FutuRaM, therefore, links the achievement of the CRMA recycling target to the need to understand the stocks, flows, and composition of waste. The infrastructural hardware of recycling—although challenged by the lack of adequate political, and even financial, support for European businesses, such as plastic recyclers—is connected to the software of information and knowledge that should inform a European industrial policy worthy of the name.

For this, according to **Pascal Leroy, Director General of the WEEE Forum**, which brings together 49 producer responsibility organisations for WEEE worldwide, this project is "part of a broader security-of-supply strategy: reducing dependence on a few non-EU suppliers for materials essential to the green, digital and defence transitions, and aligning secondary resource planning with primary raw materials policy."

The Recycling and Information Gap

One of the most significant results of the project is the estimate of **Europe's raw material capital contained in our electrical and electronic waste**, and how much of this capital is lost. In 2022, in the EU27+4 area (European Union plus Iceland, Norway, Switzerland and the United Kingdom), **10.7 million tonnes of waste electrical and electronic equipment (WEEE) were generated**, roughly 20 kg per person. These wastes contained approximately 1 million tonnes of 29 critical raw materials. However, only 5.7 million tonnes of WEEE — 54% of the total — were collected and properly treated, from which **about 0.4 million tonnes of critical raw materials were recovered**.

But let's try to flip the perspective, as when looking for "hidden" objects in an image with optical effects. Let's focus not on what we manage to recover and recycle, but on **what we are still unable to collect and recycle, even though it is right at hand**—inside our homes, on our streets, on our rooftops. Shifting from a positive to a negative view, FutuRaM tells us that, in 2022, approximately **5 million tonnes of WEEE — 46% of the total — did not enter appropriate management channels**: some ended up in improper or non-compliant recovery processes, which sacrifice the most valuable parts; some went to mixed municipal waste, some were exported for reuse, and some were even lost without a trace. And, as we know, even in correctly treated streams, a portion of critical raw materials is not recovered—particularly rare earths such as neodymium, dysprosium, yttrium, and europium, essential for magnets, fluorescent powders, and electronics. The reasons for these additional losses are technological, economic, but also informational.

A New Way of Looking at Recycling

FutuRaM attempts to change the lens through which we view recycling. It does not stop at noting that a product contains copper, aluminium, palladium, or rare earths; it highlights the industrial necessity of knowing which component they are in, what materials are associated with it, whether the component can be separated, whether a treatment technology exists, whether recovery is economically viable, and whether the regulatory framework incentivises it.

The goal is both to increase collection and to improve its quality, as **Giorgio Arienti, Director General of Erion WEEE**, Italy's producer responsibility system for WEEE, explains: "FutuRaM clearly shows that collecting more is not enough, because quantity without quality does not lead to efficient recovery of critical materials. Collecting more is certainly important, but at the same time it is crucial to collect better: selecting streams, separating materials, and reducing contamination. In practice, batteries, printed circuit boards, and electronic boards must be treated separately to maximize recoverable value."

To give substance to this statistical, intangible infrastructure, FutuRaM has produced classifications, datasets, stock-and-flow models, transfer coefficients, 2050 scenarios, and proposals to improve European statistics on secondary raw materials. It has also developed an **Urban Mine Platform** to navigate this knowledge base and "assess the availability and recoverability of secondary and critical raw materials in Europe."

All of these are tools necessary to build **competitiveness**, **resilience**, and **decarbonisation** in European industry.

"The message of FutuRaM is that WEEE, along with other types of waste analysed in the project—including batteries, vehicles, construction and demolition waste, mining waste, industrial slags and ashes, and wind turbines—represents a strategic source of secondary raw materials for Europe," says **Giulia Iattoni**, Assistant Programme Officer at the United Nations Institute for Training and Research (**UNITAR**). "Data show that significant volumes of critical raw materials are already present in waste flows and will increase further by 2050, but **their effective recovery depends on political, infrastructural, and technological choices**."

CRM in EU Electronic Waste: Knowing How Many Is Not Enough

These estimates come from the European FutuRaM project and show how much WEEE Europe produces, how many critical raw materials it contains, and why this stream is increasingly considered a strategic resource

by **Daniele Di Stefano**

Approximately **10.7 million tonnes of WEEE in 2022. That's how much Waste Electrical and Electronic Equipment European** citizens and businesses in the EU27+4 (European Union plus Iceland, Norway, Switzerland, and the United Kingdom) discarded — about **20 kg per person** on average.

At this point, we only see the problem. But taking a step further, we can also glimpse the solution: the contribution these wastes can make to **increase the autonomy of European industry**, reducing dependence on foreign supplies of **raw materials, particularly critical and strategic ones** essential for the green and digital transitions.

This step forward is made possible by the analyses, estimates, and projections conducted for the European FutuRaM project, funded by the Horizon program. These analyses show that within this WEEE there were approximately **1 million tonnes (Mt) of 29 different critical raw materials**. This is the figure that transforms mobile phones, computers, screens, washing machines, refrigerators, small household appliances, and photovoltaic panels from an environmental problem into a potential industrial resource.

According to **Giulia Iattoni**, Assistant Programme Officer at the **United Nations Institute for Training and Research (UNITAR)**, one of the project partners, "in the FutuRaM project we have collected and harmonised observed data from official sources, such as Eurostat, national reports, scientific literature, and industrial data, integrating them with mathematical models to fill the information gap. The observed data describe the current state of WEEE flows and their content of critical raw materials."

In European WEEE, there is copper in cables, aluminium in casings, rare earth elements in magnets and fluorescent powders, and platinum-group metals in electronic boards and displays. These are not marginal materials. They are inputs essential for chemistry, metallurgy, electronics, engines, energy systems, photovoltaics, electric mobility, and more generally, the green and digital transition. These are **materials that European industry needs** and that it currently seeks outside its own borders.

The Gap Between Content and Recycling

A key aspect highlighted by the FutuRaM project is that "containing" does not automatically imply the ability to "recycle" Of the **10.7 million tonnes** of WEEE, only 5.7 million tonnes (54%) were collected and sent for proper treatment. This made approximately **0.4 million tonnes of critical raw materials** available for recycling—for example: 208 kt of aluminium, 162 kt of copper, 12 kt of silicon, 1 kt of tungsten, and 2 tonnes of palladium. The remainder is lost for various reasons: failure to intercept, failure to identify materials, failure to disassemble, or technical limitations of recycling technologies.

"Not all the material present in products is actually recoverable," clarifies Iattoni, "because the **availability as a secondary resource is influenced by several factors**: some of it is not intercepted by collection systems, while some, although collected, is not technically or economically accessible with current recycling technologies, due to low concentrations or the complexity of components. A significant portion of WEEE in Europe does not enter formal collection channels compliant with the WEEE Directive, which reduces the potential for recovering the critical raw materials contained within."

WEEE and Critical Raw Materials: The Trend

Looking to the future, the volume of WEEE is expected to increase. However, if collection and recycling are properly implemented, This will represent an opportunity rather than an issue to address (for completeness, this also touches on the trade-off between environmental priorities, which encourage extending product lifespans, and industrial and strategic priorities, which require materials to be recycled). Studies prepared for the FutuRaM project (for example, the *2050 Critical Raw Materials Outlook*) estimate that in the EU27+4 area, electronic waste could increase from **10.7 Mt in 2022** to a range of **12.5–19 Mt by 2050**. Photovoltaic panels are the category with the most pronounced growth: from **0.15 Mt in 2022** to **2.0–2.2 Mt in 2050**. At the same time, the amount of critical raw materials contained in these future wastes is also expected to rise: up to **1.2–1.9 Mt**.

Iattoni further clarifies: "The modelling estimates reconstruct or complete missing information through coherent assumptions, weighted estimates, and mass balances, when possible later validated by industry experts. The future scenarios developed in FutuRaM (business-as-usual, recovery, and circularity) are not forecasts, but represent **possible developments up to 2050 based on changes in collection systems, recycling technologies, and market dynamics**, allowing an assessment of how these conditions influence the availability and recovery of critical raw materials from WEEE and the achievement of the targets."

Investing in the Quantity and Quality of Recycling

According to another report, *Future Trends of Secondary Raw Materials and Critical Raw Materials*, with appropriate recycling technologies, electrical and electronic waste could become a significant secondary source. Today, recovery mainly focuses on precious metals, copper, iron, and aluminium, but in the future, it could extend to other key elements through the disassembly of components rich in critical raw materials. "FutuRaM clearly shows that collecting more is not enough, because quantity without quality does not lead to efficient recovery of critical materials," explains **Giorgio Arienti, Director General of Erion WEEE**, Italy's producer responsibility system for WEEE. "Collecting more is certainly important, but at the same time it is crucial to collect better: selecting streams, separating materials, and reducing contamination. In practice, batteries, printed circuit boards (PCBs), and electronic boards must be treated separately to maximize recoverable value."

Reducing Dependence

The ways we can use these valuable materials help us understand what's at stake. **Copper** is used in cables, inductors, compressors, and electronic boards. **Aluminium** is used for casings and structural components. **Palladium** is used in electronic boards, hard drives, and LCD and plasma displays. **Rare earth elements**, such as neodymium, are critical for magnets; others, like yttrium and europium, are used in specific electronics and lighting applications, especially in phosphors or fluorescent powders in lamps and displays. However, the strategic value — the real significance of this analysis — can probably only be appreciated when considered in the context of **global trade flows**, and when compared to the amounts of these materials present in WEEE — copper, aluminium, silicon, tungsten, palladium, and rare earths — that European industry seeks and purchases from outside its borders.

> *"With appropriate recycling technologies, electrical and electronic waste could become a significant secondary source.*

According to the **CRIET (Interuniversity Research Centre on Territorial Economics) and Istat**, the value of Italy's imports of critical raw materials in 2023 was €1.4 billion. "The negative balance of the trade in critical raw materials provides an initial, and quite evident, indication of

Italy's vulnerability on this issue, highlighting its strong dependence on other countries for this type of supply," the authors write.

These numbers clearly explain why WEEE can no longer be viewed simply as a waste management problem. In many cases, the materials they contain coincide with those imported from a few—and not always geopolitically reliable—external suppliers. The "urban mine" often discussed does not eliminate dependence, but it can help reduce it, thereby increasing the competitiveness and resilience of continental industry.

Collection, recycling, critical raw materials: 2050 projections

	2022	2050
Total WEEE Generated	10,7 Mt*	12,5-19 Mt*
WEEE generated per person	20 kg	23,5-36,2 kg
Photovoltaic panels Total	0,15 Mt*	2,2 Mt*
Small equipment	3,2 Mt*	2,5-4,5 Mt*
WEEE collected	5,7 Mt* 54%	11-17 Mt* 54-85%
CRMs embedded in WEEE	1 Mt*	1,2-1,9 Mt*
CRMs recovered	0,4 Mt*	0,9-1,5 Mt*

* Million tonnes

Data EU27+4 — European Union, Iceland, Norway, Switzerland and the UK.
Source and projections: FutuRaM — 2050 Critical Raw Materials Outlook

The Critical Raw Materials Act in numbers

34 **critical raw materials identified by the European Commission, including 17 defined as strategic**

10% EU extraction capacity target by 2030, compared with the EU's annual consumption of strategic raw materials

40% minimum processing capacity target by 2030

25% minimum EU recycling capacity target by 2030

65% maximum share of annual EU consumption of strategic raw materials from a single third country, at any stage of processing

27 months time limit set by the CRMA for authorising extraction projects, starting from its entry into force on 23 May 2024

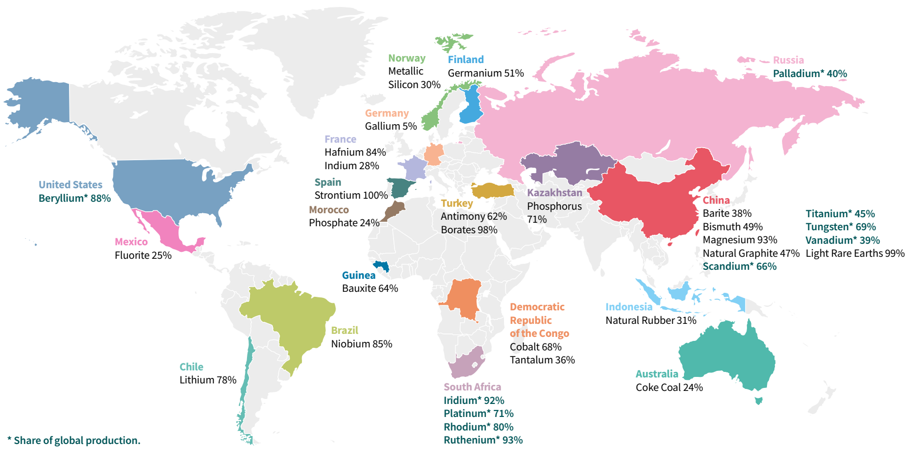
15 months time limit set by the CRMA for authorising recycling and processing projects

60 strategic projects approved under the CRMA mandate: 47 within the EU and 13 in third countries

Source: Regulation (EU) 2024/1252

European Dependencies

Countries with the highest share of Critical Raw Materials supply for the European Union [Year 2020]



Source: European Commission [2020, 474, Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability]

Improving Flows to Recycle More

The European FutuRaM project highlights urban mines as a potential resource dispersed across millions of products, components, and waste streams. It also identifies where interventions are needed to turn this potential into effective secondary supply

by **Daniele Di Stefano**

To optimize a process, it is analyzed and examined closely to identify the least efficient phases, understand the reasons for suboptimal yields, and correct errors. Today, in Europe, we purchase **a vast number of electrical and electronic equipment (EEE)** containing large quantities and a wide variety of **precious materials**, such as so-called **critical raw materials (CRMs)**: valuable in terms of environmental impacts associated with extraction, transport, and processing; valuable in terms of market costs (often influenced by complex geopolitical conditions and the concentration of extraction in a few countries); and valuable in terms of the needs of European industry, including sectors linked to **decarbonization**.

What appears to be a positive scenario—a continent that does not possess the raw materials it needs in its own subsoil but can find them in consumer goods on the market—is positive only potentially. Europe is not yet able to take full advantage of all the electrical and electronic equipment (EEE) in circulation once it becomes waste. So, what isn't working?

We know that Europe's "urban mine" is only partially an immediately available resource. Thanks to the European FutuRaM project, funded under Horizon Europe, it is now clearer that we are dealing with a **potential dispersed across millions of products, components, and waste streams**. Turning this potential into effective secondary supply requires technology, of course. But first and foremost, it is necessary to **intercept this potential**: there must be **traceability, quality of flows, the ability to know where critical raw materials are** before they are lost**, and high-quality data**.

The Heart of the Problem Lies in the Losses

In 2022, in the EU27+4 area — European Union, Iceland, Norway, Switzerland, and the United Kingdom — **10.7 million tonnes of waste** were generated from electrical and electronic equipment (WEEE), roughly 20 kg per person — a significant amount. Within this waste, approximately **1 million tonnes of critical raw materials** were embedded: copper in cables, aluminum in casings, rare earths in magnets and fluorescent powders, and platinum-group metals in electronic boards.

Here, entropy begins. Only half or slightly more — 5.7 million tonnes of WEEE, **54% — were collected and treated properly**, meaning in a way that enables the recovery of the industrial, environmental, and economic value they contain. Of the approximately 1 million tonnes of critical raw materials present in WEEE, only 0.4 million tonnes become theoretically available for recovery; 0.5 million tonnes are lost during collection, and 0.1 million tonnes during recovery. The largest loss, therefore, occurs before the treatment and recycling facility.

> *"There must be traceability, quality of flows, the ability to know where critical raw materials are before they are lost, and high-quality data.*

From these flows, approximately **0.4 million tonnes** of those valuable raw materials were made available for recovery. If we were dealing with a string of pearls whose broken thread needed replacing, we would have lost more than half. This is hardly acceptable given Europe's high demand. The gap between these numbers is at the heart of the problem, a problem that extends across all stages of the recycling value chain.

The Limits of Recycling Are Limits of the Value Chain

Those who read EconomiaCircolare.com and are aware of the very low data on the collection of electrical and electronic waste know that losses begin well before the recycling process. Yet insufficient collection alone does not explain the scale of the waste. Let's therefore take a broader view to observe the entire value chain.

The critical stages, as shown by analyses from the FutuRaM project, are at least four:

- **Collection**, where WEEE may not be intercepted;
- **Non-compliant flows**, where waste is mixed, exported, or not documented;
- **Pre-treatment**, where dismantling and separation may fail to isolate components rich in critical materials;
- **Recycling**, where some materials, especially if present in small quantities or highly dispersed, are not recovered.

How many raw materials do we recover from WEEE?

10,7 *million tonnes* **of waste electrical and electronic equipment (RAEE)**

1 *million tonnes* **of critical raw materials embedded in that stream**

0,4 *million tonnes* **of critical raw materials recovered**

2022 data, EU27+4 — European Union, Iceland, Norway, Switzerland and the UK.
Source: FutuRaM — 2050 Critical Raw Materials Outlook

Unrecoverable?
The hardest raw materials to recycle

IN WEEE		*RECOVERED*
4.300 tonnes	**Antimony (Sb)**	**100 tonnes**
4.200 tonnes	**Strontium (Sr)**	**0 tonnes**
105 tonnes	**Yttrium (Y)**	**0 tonnes**
9 tonnes	**Palladium (Pd)**	**2 tonnes**





2022 data, EU27+4 — European Union, Iceland, Norway, Switzerland and the UK.
Source: FutuRaM — 2050 Critical Raw Materials Outlook

The Missing Collection

The first point where a significant portion of the waste we are discussing occurs is collection. According to FutuRaM, in 2022 approximately **0.5 million tonnes of critical raw materials present in WEEE were lost at this stage**: 257 kt of aluminum, 187 kt of copper, 10 kt of silicon, 2 kt of tungsten, 4 tonnes of palladium, and about 9 kt of other materials, including rare earths. This is the data that shifts the focus of the discussion: **without intercepting the flows, recovery is impossible**, no matter how advanced the downstream technology is.

> *"Almost half of the WEEE generated escapes compliant management. Of the 10.7 million tonnes produced in 2022, 5 million tonnes — 46% — were not collected or treated properly.*

The reason, as mentioned earlier, is that almost half of the WEEE generated escapes compliant management. Of the 10.7 million tonnes produced in 2022, 5 million tonnes — 46% — were not collected or treated properly. Of these:

- **3.3 million tonnes** end up in **non-compliant recovery processes**, often mixed with metallic or plastic waste;
- **0.7 million tonnes** are disposed of with **mixed municipal waste**, sent to landfill or incineration;
- **0.4 million tonnes** are exported for **reuse**;
- **0.6 million tonnes disappear from the radar**, remain undocumented, and are probably illegally exported or processed through informal channels.

A Mix That Dilutes Value

The second crucial point where the European economy is deprived of its valuable WEEE—and thus of materials important for our future—lies in the **loss of quality in waste streams**. When WEEE is mixed with other waste, the system can only recover some of the simpler fractions—such as iron, steel, and sometimes copper or aluminum—while access to materials contained in complex components, often in very small quantities, is virtually impossible. It would be a mistake to think that the much-discussed "urban mine" can be reduced solely to a question of quantity: the quality of the stream reaching the facilities also matters—and matters a lot.

Pre-treatment and Information

The third weak link in the process is pre-treatment: **dismantling, cleaning, shredding, and separation**. WEEE consists of complex products made of different materials connected at the assembly level or even chemically. After selective dismantling, products or components are often shredded and separated, but the process is only partially successful: **some materials remain attached or mixed with others**, which affects the possibility of recovering them.

For this reason, it is not enough to know that a critical raw material is present in a waste item: **it is necessary to know which component contains it and whether (and how) that component can be separated from the rest**. Palladium, rare earths, tungsten, or neodymium are not uniformly distributed in WEEE. They may be concentrated in electronic boards, hard drives, permanent magnets, displays, cables, compressors, or photovoltaic cells. If these components are not identified and separated, the critical material remains hidden within the waste stream.

Recycling

And now we come to recycling, which also plays a key role in the loss of materials during its process. Even when WEEE enters the appropriate channels, not all raw materials are recovered. In 2022, despite proper collection and treatment, approximately **0.1 million tonnes of critical raw materials were not recovered**. The losses mainly concern rare earths such as neodymium, dysprosium, yttrium, and europium—materials essential for magnets, fluorescent powders, and electronics.

The reasons are both technical and economic. Some critical raw materials are present in **very small quantities**, dispersed across many products, or **incorporated into components that are difficult to process**. For example, **antimony, strontium, and yttrium** were almost entirely unrecovered in 2022; **palladium** showed a low recovery rate, with only 2 tonnes theoretically available out of 9 tonnes present. Without dedicated technologies and policies, many of these materials will continue to be lost in the future.

This highlights the crucial difference between "recovery" and "recoverability." Recovery indicates what actually occurs in the process: it measures what remains available for production purposes. Recoverability, on the other hand, indicates whether a critical raw material can potentially be recovered, taking into account technical, economic, environmental, and legal factors. A material may be present in a waste stream, **but not realistically recoverable** if it is too dispersed in other materials, if mature recovery technologies are lacking, if the flow is of low quality, or if economic conditions do not make recovery profitable.

The Crucial Role of Data

If the technical aspect is, as is well known, extremely important, the same applies to information: even data—**the limited availability of data**—**is part of the problem**. If the composition, components, quality, and fate of flows are not known, it is difficult to estimate which materials are lost, where, and where intervention is worthwhile. This is also the role of the FutuRaM project, whose results highlighted the difficulties caused by **insufficient availability and poor granularity of data**: information is missing for certain product groups, at some levels of the product-component-material-element hierarchy, or for specific components. To assess tantalum in a laptop, for example, and then recycle it, it is not enough to know that there is an electronic board in the product: one must know whether there are tantalum capacitors.

The issue, as is often the case, also involves measurement, and is therefore statistical. **The analysis of material flows**, which the European project focuses on, is used to estimate not only the quantity of secondary raw materials available, but also their location, quality, and accessibility. For critical raw materials, where primary supply may be limited by geopolitical, economic, and environmental constraints, monitoring stocks and flows across the entire life cycle—extraction, production, use, end-of-life, and recovery—becomes essential for unbiased public decision-making, avoiding short-sightedness or tunnel vision.

How to Reduce Gaps in the System

This leads to the proposal to improve statistical classification codes. Among the recommendations of the European project is to "**adapt the PRODCOM** (the annual EU-harmonised industrial production survey) and **EU List of Waste** codes to improve capture of data for secondary raw materials". This would involve adding 30 new codes to the PRODCOM classification and 43 to the EU Waste List. These codes would specifically aim to capture "components that can be dismantled during waste management and have a high critical raw material recovery potential and are mentioned in Article 26 of the **CRM-Act**, such as waste printed circuit boards, permanent magnets containing rare earth elements, black mass, and batteries that can be prepared for reuse."

The solutions proposed within the FutuRaM project obviously target all stages where significant losses have been observed. They are as follows:

- First, **increasing compliant collection**: more WEEE entering official channels means more materials potentially available for recovery.
- Second, **improving source separation and stream quality**, preventing electronic equipment from being mixed with metal, plastic, or general waste.
- Third, **identifying and separating components rich in critical raw materials** before they are shredded or dispersed.
- Fourth, addressing the upstream phase of the value chain and **product design**: equipment that is easier to disassemble, repair, and separate allows better recovery of strategic components.
- Fifth, focusing on data, so that **gradually harmonized, granular, and comparable information** becomes available, collected according to common classifications and standardized product/component lists. Digital Product Passports, Battery Passports, composition reports, Bills of Materials, and harmonized classifications can make visible what is currently lost in the complexity of waste streams.
- Sixth, concerning **facilities and industrial policies**: Europe needs recovery capacity, more selective technologies, economic incentives, and planning that links collection, treatment, and industrial demand for secondary raw materials.

From Content Data to Recycling

The difference between potentially recyclable and actually recoverable material is at the heart of the European FutuRaM project, which has measured this gap in terms of tonnes of critical raw materials lost — also highlighting the measures needed to reduce this waste

by **Daniele Di Stefano**

Inside an old smartphone, a decommissioned washing machine, a discarded monitor, or an end-of-life photovoltaic panel, there may be **copper, aluminum, palladium, silicon, tungsten, and rare earth elements**. All of these are crucial materials for the green and digital transition, yet in Europe they are exposed to supply risks and a high dependency on external suppliers. And it is precisely this dependency that makes waste electrical and electronic equipment (WEEE), such as those just mentioned, a potential reservoir of these valuable raw materials. From there, we could procure materials to meet the needs of decarbonization and the electrification of society and the economy. But the question is not only how much critical raw material (CRM) WEEE contains. The decisive question is rather: **how much of that material can we actually recover?**

The difference may seem technical, but it is political, industrial, and environmental. A material can be present in waste and yet be almost unreachable: dispersed in tiny quantities, embedded in miniaturized components, mixed with other materials, lost in non-compliant collection, or sent to treatments that only recover the easiest fractions. The European FutuRaM project, funded under the EU Horizon Europe program, seeks to make explicit and measurable the gap between content and recoverability. It is not enough to know "how much material there is": it is necessary to know **where it is located, how it is bound to the product, and what happens when that product becomes waste**.

For this reason, according to **Pascal Leroy, Director General of the WEEE Forum** (a not-for-profit association of 49 WEEE producer responsibility organisations across the world), FutuRaM is "part of a broader security-of-supply strategy: reducing dependence on a few non-EU suppliers for materials essential to the green, digital and defence transitions, and aligning secondary resource planning with primary raw materials policy."

Aiming for Recoverability

Critical raw materials are present in electrical and electronic waste (WEEE), that much we know. But that is not enough. The decisive point is to understand **where they are located**, **in which specific component**, **in what form**, how dispersed they are, and whether collection and treatment systems can intercept, separate, and direct them to recycling without losses. "The mere presence of a material in WEEE does not imply its actual recoverability. Recoverability depends on several enabling factors—or, conversely, barriers: product design, concentration and distribution of materials, available recycling technologies, economic feasibility, and collection and pre-treatment systems." tells EconomiaCircolare.com **Giulia Iattoni, Assistant Programme Officer at the United Nations Institute for Training and Research (UNITAR). "**Some materials already achieve **high levels of recovery** today thanks to favorable properties and well-established technologies. Others represent flows with **growing strategic interest and recovery potential**, linked to the evolution and market penetration of the products containing them and to existing treatment processes. Conversely, some materials remain **difficult to recover** due to their dispersion within products and current technological limits, and are recovered only in limited quantities or through processes still under development."

The FutuRaM project shifts the focus from mere "content" to "recoverability." As summarized in one of the project's deliverables (*D3.1 Extended Waste Stream Composition Assessment to Enable Secondary Raw Material Assessment*), "**composition data** is essential for understanding which strategic and critical raw materials are present in the waste streams, where they are located, e.g. in which components or materials, and how they can be recovered."

A "Messy" Urban Mine

The *2050 Critical Raw Materials Outlook* report provides illuminating data on this. In 2022, within the EU27+4 area (European Union, United Kingdom, Iceland, Norway, and Switzerland), **10.7 million tonnes of WEEE were generated — roughly 20 kg per person**. These waste streams contained about **1 million tonnes** of 29 materials that the EU has classified as **critical raw materials**: "Materials of high importance to the EU economy and of high risk associated with their supply." The report cites very concrete examples: **copper in cables, aluminum in casings, rare earths in magnets, and platinum group metals in electronic boards and displays**. We have learned to consider WEEE as an "urban mine," but it is essential not to forget that it is a "messy urban mine," composed of diverse items, components glued, soldered, miniaturized, or difficult to access.

The difference between content and recoverability becomes clear with a simple question: if an old laptop or a monitor contains copper, palladium, or rare earths, are these materials automatically and easily recoverable? Not at all.

A Hierarchical Approach to Raw Materials

The recoverability of critical raw materials depends on several factors, which, ideally, should be considered during the product design phase. **It depends primarily on their location**. A material in a cable that can be easily separated does not share the same fate as an element dispersed in tiny quantities within a circuit board, a magnet, a display, or a composite component. For this reason, FutuRaM adopts an **approach that follows a hierarchical structure**: product, component, material, element. In other words, it does not simply record that a WEEE item contains a certain amount of copper, aluminum, or rare earths; it aims to reconstruct where these materials are located within the product, moving step by step from a higher-level to a lower-level hierarchy.

In the approach employed by the project, each element (neodymium, for example) is linked to a material (permanent magnet), each material to a component (hard disk), and each component to a product (laptop). The document also specifies that the dataset of electrical and electronic equipment/WEEE created for the project covers **80 components, 23 materials, and 64 elements**, precisely to map their composition in a highly granular way.

This hierarchical approach can be decisive because **WEEE are complex, multi-material objects**. Recycling does not consist of simply "melting everything down" to automatically obtain high-quality secondary raw materials. First, the materials must be "liberated": dismantled, separated, shredded, and sorted. Each step can generate losses. The *"Extended Waste Stream Composition Assessment"* document explains that the possibilities and limits of recycling are **"strongly influenced by the performance of the liberation and separation processes."** It also notes that these processes are often "only partially successful," leaving valuable materials fixed or mixed together due to connections established during the design phase.

> *"The recoverability of critical raw materials depends on several factors, which, ideally, should be considered during the product design phase.*

Recoverability or Recovery? The Data

This is where "recoverability" and "recovery" diverge: "While recovery and recycling measure the efficiency of obtaining a constituent or material after processing or waste treatment, recoverability addresses the potential to recover that constituent or material in the first place." **Recovery measures the efficiency of the process**—it quantifies the actual outcome achieved—whereas recoverability stops earlier, at the theoretical potential for recycling. It evaluates whether a material can be recovered, with which technologies, at what costs, and under which regulatory or environmental constraints.

What may seem like a purely terminological distinction actually translates into sometimes striking results.

Looking at 2022, of the **10.7 million tonnes of WEEE generated** in the EU+4, **only 5.7 million tonnes — 54%** — were properly collected and treated. From these streams, approximately **0.4 million tonnes of critical raw materials** were recovered, including 208 kt of aluminium, 162 kt of copper, 12 kt of silicon, 1 kt of tungsten, and 2 tonnes of palladium. However, even within properly managed flows there are losses: around **100,000 tonnes of CRMs** were not recovered, particularly rare earths such as neodymium, dysprosium, yttrium, and europium, which are present in magnets, fluorescent powders, and electronic components.

The largest losses, however, occur even before treatment: during collection. In 2022, **46% of WEEE** — around **5 million tonnes** — did not enter proper collection and treatment channels. Part of it ended up in non-compliant recovery processes, where only the easier-to-recover materials such as iron or steel could be extracted, often at lower standards; **0.7 million tonnes** went to mixed municipal waste, and therefore to landfill or incineration; **0.4 million tonnes** were exported for reuse; the rest is "undocumented," likely exported illegally or treated through informal channels.

Here, critical materials are present — it's the collection system that's lacking.

Technical and Economic Aspects of Recycling

To put things in perspective, **copper** and **aluminum** are already recovered at a significant scale, partly because they are present in more recognizable components or fractions, such as cables, casings, and frames. Yet even for these materials, not everything is straightforward: internal cables or very small components can be difficult to handle. Some critical materials, on the other hand, are present in small quantities, dispersed, or embedded in components that are hard to separate. This is the case for **rare earth elements in permanent magnets**, fluorescent powders, or **certain precious metals in electronic boards and displays**.

As the report notes, "CRMs with low mass fractions/grades and content in products and waste flows, small amounts/tonnages and high dissipation generally showed lower recoverability." In these cases, recycling is indeed **a challenge—both technically and economically**: if the material is sparsely concentrated, if the flows are small or variable, if there is no stable market or no specific legal recovery obligation, the recovery operation may not be cost-effective.

The Palladium Paradox

A striking example is palladium. In WEEE, Pd—its symbol in the periodic table—is mainly found in electronic boards, hard disks, and LCD and plasma displays. According to FutuRaM estimates for 2022, about 2 tonnes of palladium were recovered, while 4 tonnes (double that amount) were lost during collection, and 3 tonnes were lost during treatment and recovery. **Consequently, only slightly more than one-fifth is theoretically available for recovery.** We are therefore facing a paradox: the majority of this high-value material is lost because it does not enter the correct stream or is not properly separated.

Future estimates predict improvements, but not fully decisive ones. By 2050, with an estimated 6–12 tonnes of palladium per year in WEEE (depending on the scenario), the theoretically recoverable share is projected to be between 2 and 9 tonnes.

One of the project reports explains: "**The recoverability of platinum, palladium and rhodium from the catalysts in ELVs** is well established due to their high economic value and concentrated presence in catalysts. However, fluctuating precious metal prices and the need for efficient dismantling and processing technologies remain important factors influencing recovery efficiency."

Estimates for 2050

Overall, the 2050 forecasting models employed by the European project confirm that increasing collection volumes alone will not be sufficient: the system as a whole needs to be improved. According to FutuRaM, the quantity of WEEE in the EU27+4 area could rise from **10.7 Mt in 2022** to a range between **12.5 and 19 Mt**. The critical raw materials contained in WEEE could increase to **1.2–1.9 Mt.** The share available for recovery could reach **0.9–1.5 Mt**, but significant losses would remain: between 200,000 and 800,000 tonnes during collection, and between 100,000 and 200,000 tonnes during recovery. Therefore, even in the best-case scenario, the urban mine will not empty itself: the waste it contains must be redesigned, collected, dismantled, and treated properly.

As Iattoni explains, "the future scenarios developed in FutuRaM (business-as-usual, recovery, and circularity) are not forecasts, but represent possible developments up to 2050 based on changes in collection systems, recycling technologies, and market dynamics, allowing an assessment of how these conditions influence the availability and recovery of critical raw materials from WEEE and the achievement of the targets."

Why are these estimates important? According to the Director General of the WEEE Forum, they will allow "**to set realistic yet ambitious targets** for CRM recovery, eco-design, collection and recycling in implementing the CRMA (e.g. Articles on recovery from extractive waste and products containing CRMs) and in revising waste and product legislation (WEEE, batteries, ELV, construction)."

They will also allow to "**prioritise waste streams and technologies with the highest recoverable CRM potential** when allocating EU funding, designating Strategic Projects under the CRMA, or designing Industrial Accelerator Act (IAA) support measures for low-carbon, EU-origin materials."

A Range of Necessary Interventions

The solution outlined in the documents is not — and could not be — a single one, but a chain of measures.

Here are the steps listed below:

Increase compliant collection, because materials that do not enter the formal collection and treatment system are unlikely to become secondary raw materials. **New sorting technologies** (such as LIBS—Laser-Induced Breakdown Spectroscopy—or XRF—X-Ray

Fluorescence, useful tools for distinguishing compositions, materials, and alloys) can help, but they do not replace proper collection, source separation, and design for disassembly.

Identify products and components rich in critical raw materials, to direct them towards targeted treatment processes.

Design products for easier disassembly, because ecodesign aimed at separation helps prevent valuable materials from being lost in mixed waste streams or undifferentiated shredding. **Labelling** will also be important: to know, possibly through the **digital product passport**, which and how many raw materials are in the waste and where they are located (and potentially how to separate them from other components).

Create economic and regulatory conditions that make CRM recovery profitable, even when they are present in small quantities or embedded in components that are difficult to separate.

> “ *Labelling will also be important: to know, possibly through the digital product passport, which and how many raw materials are in the waste and where they are located.*

Strengthen data infrastructures. Data themselves are, in fact, part of the recycling infrastructure. If producers, collective systems, treatment facilities, and authorities do not use compatible classifications and vocabularies for products, components, materials, and codes, it will be difficult to know where to intervene and which fractions to direct toward targeted recovery. Harmonized composition data, granular enough to reflect the separability of parts containing critical raw materials, will be needed. Tools such as the digital product passport will also be necessary to convey this information.

2050: When the Energy Transition Also Becomes an End-of-Life Challenge

The goal of decarbonization and the energy transition will bring with it a massive amount of electrical and electronic waste. The European FutuRaM project provides some of the conceptual tools needed to ensure that this growth does not remain just a waste management issue

By **Alessandro Coltrè**

When discussing the energy transition, we usually focus on CO2, electrification, photovoltaic panels, electrolyzers, and energy storage. But there is often a major absentee, a silent yet crucial player, as the European FutuRaM project reminds us. The energy transition is not only about production, consumption, and emission reductions; it also involves — particularly in Europe and Italy — **the management of electrical and electronic waste (WEEE).** Europe is a major market for a range of products containing critical raw materials (CRMs) essential for electronics, electric mobility, photovoltaics, and other strategic technologies.

Waste and Raw Materials

The analyses produced for the European FutuRaM project provide extremely useful data to understand both the present and future of the challenge Europe faces in transforming — effectively and beyond rhetoric — this waste into material streams that enable the energy transition.

Let's introduce some key figures. As previously reported, in 2022, across the EU27+4 area (European Union, Iceland, Norway, Switzerland, and the United Kingdom), **10.7 million tonnes of WEEE** were generated, containing approximately **1 million tonnes of critical raw materials (CRMs)**: copper in cables and inductors, aluminum in casings, rare earths in permanent magnets and fluorescent powders, platinum-group metals in electronic boards and displays, silicon in photovoltaic panels, and tungsten and vanadium in specialized components. But due to several factors — limits related to collection, the maturity of recycling technologies, equipment design, and information on the presence, distribution, and concentration of critical raw materials (CRMs) — only **400 thousand tonnes of critical raw materials** were made available for recycling. Even this partial recovery contributes to Italy's and Europe's dependence on foreign sources, often from geopolitically problematic countries, although the Hormuz crisis reminds us that, in the new global scenario, there may be no entirely non-problematic countries.

FutuRaM analyses take us to 2050. **Giulia Iattoni, Assistant Programme Officer at the United Nations Institute for Training and Research (UNITAR) explains:** "The future scenarios developed in FutuRaM are not forecasts, but represent possible developments up to 2050 based on changes in collection systems, recycling technologies, and market dynamics, allowing an assessment of how these conditions influence the availability and recovery of critical raw materials from WEEE and the achievement of the targets".

The Three Scenarios in FutuRaM

For 2050, FutuRaM has defined **three main scenarios**:

Business-as-Usual (BAU): Projection of current trends. Generated WEEE reaches 19 Mt, driven by strong growth in electronic products and photovoltaic panels. Recovery of CRMs remains limited to current technological capacities.

Recovery (REC): This scenario includes advanced recycling technologies and more efficient collection. The quantity of generated WEEE is similar to the BAU scenario, but the fraction of recoverable CRMs increases thanks to more targeted dismantling and sorting.

Circularity (CIR): This scenario promotes extended product lifetimes, reuse, and repair, reducing total WEEE generation to 12.5 Mt. The fraction recovered increases because the flows are of higher quality and more traceable, although the overall volume of waste is lower.

In summary, FutuRaM estimates indicate that the quantity of WEEE in the EU27+4 area could increase from **10.7 Mt in 2022** to a range between **12.5 and 19 Mt** by 2050. Critical raw materials contained in WEEE could rise to **1.2–1.9 Mt.** The fraction available for recovery could reach **0.9–1.5 Mt**, yet significant losses would remain: between 200,000 and 800,000 t during collection, and 100,000–200,000 t during recovery. So even in the best-case scenario, the urban mine won't yield its resources automatically: the waste it contains must be deliberately redesigned, collected, dismantled, and processed properly.

Hierarchy and Transfer Coefficients

To outline these possible futures, analysts developed a methodology that combines stock-and-flow models with POM (placed-on-market) data to estimate WEEE and CRMs up to 2050. The model tracks materials along a hierarchy from macro to micro (product–component–material–element).

A key element of the FutuRaM method is the **transfer coefficients**: parameters that estimate, for each material or component in WEEE or other waste, the fraction that is **retained, recovered, or lost** at every stage of the value chain (collection, dismantling, shredding, separation, recovery). They allow the composition of products to be translated into an estimate of the **theoretical recoverability of critical raw materials**. They can also be used to model future scenarios and calculate the **mass balance** of material flows up to 2050.

What is evident is that **the energy transition brings new waste streams that will feed an urban mine of strategic materials**. However, if we do not want this mountain of waste to remain merely a problem and instead turn it into an industrial and strategic opportunity, we will need to deploy **planning, advanced technologies, adequate compliant collection, component identification, and granular data** to monitor the quantity, quality, and accessibility of these materials.

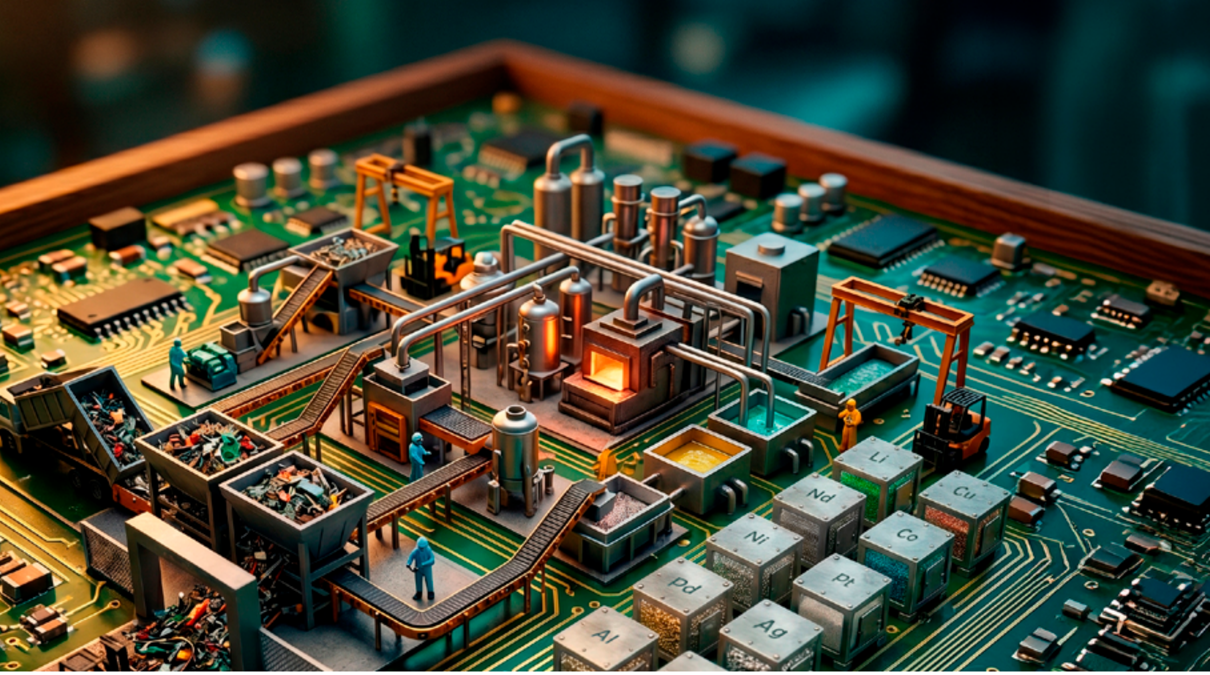
For this reason, according to **Pascal Leroy, Director General of the WEEE Forum**, which brings together 49 producer responsibility organisations for WEEE worldwide, FutuRaM is "part of a broader security-of-supply strategy: reducing dependence on a few non-EU suppliers for materials essential to the green, digital and defence transitions, and aligning secondary resource planning with primary raw materials policy".

How much will be recycled in 2050?

		2022	2050
	**Copper**	162 kt*/year	307-533 kt*/year
	**Aluminium**	208 kt*/year	506-806 kt*/year
	**Silicon**	12 kt*/year	17-28 kt*/year
	**Tungsten**	1 kt*/year	1-3 kt*/year
	Palladium	2 t/year	2-9 t/year

* Kt= 1.000 tonnes

Data EU27+4 — European Union, Iceland, Norway, Switzerland and the UK.
Source and projections: FutuRaM — 2050 Critical Raw Materials Outlook



From Urban Mines to Industrial Strategy

Dependence on critical raw materials is not reduced solely through mining, trade agreements, or fast-track authorizations. It also requires building public and industrial capacity to understand the European "urban mine" as a strategic infrastructure.

by **Raffaele Lupoli**

The new phase of Europe's critical raw materials strategy has brought an important awareness: it is necessary to know not only how much material is present in electrical and electronic equipment, but also **where it is, in which components, with what level of recoverability, in which year it will become available, and with which technologies** it can re-enter the economy. This is where a seemingly technical project like FutuRaM, supported by the European Union, intersects with the heart of the Old Continent's industrial policy. Dependence on critical raw materials is not reduced simply by opening mines, signing trade agreements, or fast-tracking authorizations. It is also reduced by building public and industrial capacity to understand the **European "urban mine" as a strategic infrastructure.**

The **Critical Raw Materials Act (CRMA)** sets ambitious 2030 targets for extraction, processing, recycling, and reducing dependency. However, the real goal is to translate those targets into actionable policies and guidelines, facilities, shared and interoperable data, fast-track authorizations, secondary markets, recovery capacities, and the construction of value chains capable of keeping processing and transformation of products within European borders.

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The New Geography of Industrial Security

As is well known, critical raw materials are essential for renewables, energy storage, digital technologies, aerospace, and defense. In this context, the European Commission reports that European demand for **rare earths** could grow sixfold by 2030 and sevenfold by 2050, while **lithium** demand could increase twelvefold by 2030 and twenty-onefold by 2050. However, Europe's challenge is not simply its dependence on imports of these raw materials. The real vulnerability lies in the fact that key stages of the value chain—such as **refining, separation, magnet production, and component manufacturing**—are concentrated outside the European Union. The risk, therefore, is that Europe may finance decarbonization and the so-called "twin transition" without possessing sufficient industrial levers to govern it. This is why it is crucial to implement a raw materials policy that combines strategic autonomy, economic security, sustainability, and industrial policy.

The CRMA acts on multiple levels: lists of critical and strategic raw materials, Strategic Projects, faster authorisations, stress tests, supply chain monitoring, national exploration programmes, recovery from waste and extractive residues, requirements on permanent magnets, and increased circularity. For projects selected as "Strategic Projects," the regulation also provides support for access to finance and shorter authorisation timelines: 27 months for extraction permits and 15 months for processing and recycling. This represents a profound transformation of the public role. The aim is to **directly shape the architecture of value chains**, but here the first bottleneck emerges. Without reliable data on available secondary resources, losses along the value chain, and priority components, **European policy risks operating between ambitious targets and insufficient operational capacity**.

The Urban Mine as a Knowledge Infrastructure

The first testbed came in 2025 with the selection of Strategic Projects. The Commission approved those located within the EU on 25 March 2025 and those outside the EU on 4 June 2025: they concern the extraction, processing, recycling, and substitution of 14 strategic raw materials. The **47 projects within the European Union** are designed to strengthen domestic capacities for strategic raw materials, while the first **13 projects outside the EU** aim to diversify supply sources. This represents a strong push to reduce the riskiest dependencies, build capacity in currently weak segments, and leverage the Single Market to support projects across the entire value chain. This push requires rapid timelines but clashes with the need to initiate exploration of new extraction facilities, authorize recovery, processing, and transformation plants, secure capital, expertise, and technologies, as well as properly consider community involvement and the social acceptability of the proposed infrastructure. The **European Court of Auditors**, in its Special Report on critical raw materials and the energy transition, warned that measures to diversify imports, increase domestic production, and improve resource management are still not producing sufficient results to secure the process. This is why **urban mines become a**

decisive terrain, as they can reduce pressure on global markets, lower vulnerability, and **create European value chains less exposed to geopolitical shocks, likely in a shorter timeframe than primary supply**.

The FutuRaM project sits squarely in this gray area between knowledge, statistics, and industrial policy, developing a knowledge base on secondary raw materials with a particular focus on critical ones. It produces highly useful datasets, but above all it directs **attention to the specific understanding of the flows, the components in which materials are contained, and their recoverability**. This information, in turn, allows focus on the technical and economic chain needed to truly valorize urban mines. An electronic board, a permanent magnet, an electric motor, a battery, or a photovoltaic panel are not equivalent from a recovery perspective. They differ in material concentration, dispersion, disassembly feasibility, available technology, economic value of the recoverable fraction, applicable regulations, and market presence. Here, the connection with the CRMA becomes direct. If Europe wants to reach a 25% recycling capacity relative to annual strategic raw material consumption, **it must know which flows can realistically contribute to that goal**.

From Raw Materials Diplomacy to Aggregated Demand

Along this line of action is the creation, by the European Union, of common market instruments. The **Raw Materials Mechanism**, part of the EU Energy and Raw Materials Platform, was launched in November 2025 with the goal of connecting industrial demand, global suppliers, financial institutions, and storage solutions. The Commission describes it as a tool to aggregate demand, promote joint purchasing, develop strategic projects, and connect off-takers (producers committed to supplying a good at a set price for a defined period) with investors.

Beyond promoting partnerships or funding individual projects, the EU is therefore seeking to build a **collective capacity for purchasing and demand coordination**, in order to support companies that, on their own, lack sufficient bargaining power, time horizon, or financial instruments to carry out projects alternative to supply chains dominated by large non-European players.

But here too, the secondary dimension is decisive. If the platform is used only to better purchase primary raw materials, it will remain a diversification tool. If, however, it manages to include secondary raw materials, off-take agreements for recovered materials, strategic stocks, and data on waste hotspots, it can become a component of industrial circular policy. FutuRaM provides the informational support for this leap: the **Urban Mine Platform** is designed to integrate datasets useful for identifying material hotspots and supporting coherent policies for the recovery of critical and strategic raw materials.

Clean Industrial Deal and Industrial Accelerator Act

The strategy on critical raw materials does not advance in isolation. The Clean Industrial Deal, presented by the Commission on 26 February 2025, was designed to **turn decarbonization into a driver of industrial growth**, with a focus on energy-intensive industries—steel, metals, chemicals—and cleantech. Within this framework, circularity is explicitly highlighted as a tool to reduce waste, extend the lifespan of materials, and decrease dependence on non-EU suppliers of raw materials. The subsequent **Industrial Accelerator Act**, proposed by the Commission on 4 March 2026, pushes this logic even further. The new measures target strategic sectors such as steel, cement, aluminum, automotive, and net-zero technologies, with the possibility of extension to other energy-intensive industries. The goal is to accelerate industrial capacity and decarbonization, also through faster and digitalized permitting procedures.

The link with critical raw materials is deeper than it might seem at first glance. If Europe wants to revive clean manufacturing, batteries, electric vehicles, renewables, electrolyzers, semiconductors, defense, and data centers, it will need to **manage three markets simultaneously: energy, technology, and materials**. In this sense, the Clean Industrial Deal and the CRMA are two facets of the same policy: the first aims to create demand and industrial capacity, while the second seeks to secure the material inputs for that capacity.

The risk, however, is that public or incentivized demand focuses solely on "Made in Europe" content without a sufficient European infrastructure for secondary materials. Rewarding European products made with critical raw materials imported from fragile or concentrated supply chains would not truly make the EU economy resilient. European industrial policy will therefore need to **avoid an artificial separation between manufacturing and recycling**, between final product and raw material, and between green public procurement and recovery capacity.

RESourceEU: Between Economic Security and Circularity

RESourceEU also plays a prominent role within the European framework of initiatives designed to accelerate the creation of a European market and value chain for critical raw materials. This action plan was adopted by the European Commission in December 2025 **as the application of the REPowerEU logic to raw materials: reducing deep dependencies through diversification, financial instruments, public-private coordination, and shared operational capacities.** RESourceEU introduces or strengthens tools such as a European Critical Raw Materials Centre, a coordinated approach to stock management, a joint procurement mechanism via the Raw Materials Platform, and measures to reinforce the secondary market, particularly for permanent magnets and critical materials linked to strategic industrial sectors.

Europe has begun to build the framework: CRMA, Strategic Projects, Raw Materials Mechanism, RESourceEU, Clean Industrial Deal, Industrial Accelerator Act. It now needs to ensure that these tools do not operate in parallel without integration. Reducing dependency will not be the result of a single regulation, but of the **ability to connect industrial policy, circularity, and material knowledge**. This is where FutuRaM intersects with European policies, providing the informational conditions so that strategic autonomy does not remain a slogan and the new European industrial policy does not become a victim of the materials it should be learning to govern.

Italy's Strategic Autonomy Is Still to Be Played

Italy is still far from closing the loop on the electrical and electronic waste (WEEE) supply chain and the valuable materials it contains. The greatest value lies precisely in the downstream stages that are missing in our country—and more broadly across Europe.

by **Raffaele Lupoli**

For Italy, the critical raw materials challenge is practically at kickoff. The tentative signs of improvement in collection are not enough to bring the country closer to European targets: according to the 2024 WEEE Management Report, prepared by the Italian WEEE Coordination Centre (CdC RAEE) to monitor household and professional WEEE sent for recycling and processed in facilities, the collection rate stands at **29.64%, against an EU target of 65%** in force since 2019. But unfortunately, this is not the only critical issue in the system. **Giorgio Arienti, Director General of Erion WEEE**, explains to EconomiaCircolare.com that even today, "in Italy, there is still a lack of complete and standardized data, advanced recycling infrastructure, and integrated industrial processes, which means that a large portion of the critical materials present in WEEE is either exported or lost, resulting in economic and technological losses."

The game therefore begins in our drawers full of cables, appliances, and devices that need to be disposed of correctly, but it must necessarily continue by **looking beyond collection**—which certainly needs significant strengthening—to create a system capable of building national value chains that retain value.

An Industrial Value Chain Yet to Be Built

Fortunately, awareness is growing — for now more within civil society than in political action — that WEEE is no longer merely a waste stream to be properly managed, but a **component of industrial policy**. A policy that is yet to be built, and that must be based on planning grounded in data and projections, as [FutuRaM](), the **Horizon Europe project** dedicated to the future availability of secondary raw materials, attempts to do. Not all critical raw materials behave in the same way. Aluminum and copper, present in larger quantities and more consolidated fractions, are already recovered at a significant scale. Elements such as neodymium, dysprosium, palladium, or tungsten, however, require component identification, selective dismantling, dedicated technologies, outlet markets, and stable volumes. Projections for the growth of WEEE — particularly photovoltaic panels, but not limited to them — **make a coordinated European-level strategy even more necessary**, to identify, country by country, and therefore also in Italy, which flows should be treated and, ideally, reintegrated into the production system within European borders.

> “
> *Fortunately, awareness is growing — for now more within civil society than in political action — that WEEE is no longer merely a waste stream to be properly managed, but a component of industrial policy.*

Saying “recycling” alone is therefore not enough. One must examine each individual electrical and electronic device once it becomes waste to understand its full potential in detail, while also ensuring there are sufficient materials to make the creation of processing facilities economically viable and to identify the industries interested in using them.

The System Can’t Run Without Stable Flows

The **President of the CdC RAEE, Giuliano Maddalena**, introducing the 2025 Annual Report, highlights that the system is well-established, but territorial differences “keep Italy far from the European targets for interception.” Indeed, the numbers for domestic WEEE collection tell a familiar story of highly uneven performance: the North reaches 192,952 tonnes and 7.02 kilograms per capita (kg/inhabitant), the Center 85,854 tonnes and 6.61 kg/inhabitant, while the South reaches 88,085 tonnes and 4.76 kg/inhabitant. Campania, with 2.95 kg/inhabitant, remains the national laggard.

Increasing collection means stabilizing waste flows. And without stable flows, the possibility of establishing advanced treatment facilities diminishes. Arienti clarifies that today many Italian plants are limited to separating high-value components, such as electronic boards and printed circuits, which are **then exported to countries equipped with more advanced technologies**. Italy, therefore, is still far from closing the loop. The greatest value lies precisely in the downstream stages that our country—and Europe more broadly—still lacks: refining, fine separation, recovery of elements present in small quantities, and the production of materials and components for new industrial supply chains.

What Is Needed to Retain Value in the Country

For industry insiders, **the case of neodymium has become paradigmatic**. This element is essential for producing permanent magnets found, for example, in smartphones, wind turbines, hybrid and electric vehicle motors, and computer hard drives. If an Italian company recovers it from WEEE, it will have to export it for processing, and the component containing it will then need to be purchased—almost always from non-European companies.

> “
> *Creating an industrial demand for the recovered materials is an urgent issue that our country must address in coordination with other European nations.*

Creating an industrial demand for the recovered materials is an urgent issue that our country must address **in coordination with other European nations**. Meanwhile, without value chain agreements, long-term contracts, technical standards, and manufacturing outlets, secondary raw materials continue to be an accounted-for resource but remain unexploited.

The barriers identified by the European FutuRaM project accurately reflect the Italian situation: recycling infrastructure is lacking for emerging flows such as lithium-ion batteries, electric vehicles, NdFeB (Neodymium-Iron-Boron) magnets, and photovoltaic panels; there are no adequate specific recovery targets or end-of-waste criteria; and materials present at low concentrations exhibit weaker recoverability if they are not concentrated in separable components.

This highlights the importance of **ensuring traceability and data availability**, including through **digital product passports**, the **Battery Passport**, and **interoperable reporting systems** — essential tools to prevent critical raw materials from remaining invisible within complex products.

An invisibility we can no longer afford, given the dual urgency of safeguarding our country’s strategic autonomy and addressing the imbalances caused by the overexploitation of natural resources.

WEEE FORUM

WATCH THE VIDEO

“FutuRaM is an enabling layer for EU CRMs regulations”

Interview with Pascal Leroy, Director General of the WEEE Forum, a not-for-profit association of 49 WEEE producer responsibility organisations across the world: “FutuRaM supports implementation of Critical Raw Materials Act obligations on recovery and circularity.”

by **Raffaele Lupoli**

Pascal Leroy, as Director General of the WEEE Forum, could you explain why FutuRaM can be considered a strategic project for Europe, rather than just a research project on waste?

The EU has moved from discussing CRMs to imposing binding benchmarks under the **Critical Raw Materials Act** for extraction, processing and recycling, including a **25% recycling benchmark for strategic materials by 2030**; meeting these requires knowing where secondary CRMs are, in what quantities and under which conditions they can be recovered.

FutuRaM responds by building a **Secondary Raw Materials** (SRM) knowledge base and **UNFC**-based assessment framework for key waste streams (batteries, WEEE, vehicles, mining waste, slags/ashes, construction & demolition), directly supporting implementation of CRMA obligations on recovery and circularity.

This makes FutuRaM part of a broader **security-of-supply** strategy: reducing dependence on a few non-EU suppliers for materials essential to the green, digital and defence transitions, and aligning secondary resource planning with primary raw materials policy.

What knowledge gap does it aim to fill with regard to critical raw materials, the circular economy and strategic autonomy?

Before FutuRaM, the EU had fragmented, non-comparable data on CRMs in waste streams, with limited ability to link product stocks, flows, recycling performance and future availability scenarios in a coherent, open framework.

FutuRaM explicitly aims to "**improve the raw materials knowledge base**" by harmonising methodologies, reporting structures and guidance on SRM/CRM availability and recoverability up to 2050, integrating economic, technological, regulatory, social and environmental dimensions.

In CRM and circular-economy terms, the gap is threefold: (i) **Where** and in what concentrations CRMs are present across the six waste streams today and in future (stocks and flows, including WEEE). (ii) **How much** is technically and economically recoverable under different policy and technology scenarios, and which projects are viable when assessed via UNFC. And (iii) How to make this **information accessible** (e.g. via an open knowledge base and upgraded Urban Mine Platform) so it can guide real-world investment and policy choices rather than remain in isolated studies.

How can the project's results be used in concrete terms by policymakers, consortia and industrial supply chains?

Policymakers:

- Use the SRM knowledge base and 2050 CRM outlooks to set realistic yet ambitious targets for CRM recovery, eco-design, collection and recycling in implementing the CRMA (e.g. Articles on recovery from extractive waste and products containing CRMs) and in revising waste and product legislation (WEEE, batteries, ELV, construction).
- Prioritise waste streams and technologies with the highest recoverable CRM potential when allocating EU funding, designating Strategic Projects under the CRMA, or designing **Industrial Accelerator Act** (IAA) support measures for low-carbon, EU-origin materials.

Producer responsibility organisations:

- Use FutuRaM data to identify where higher collection, pre-treatment or specialised recovery would yield the greatest CRM gains per euro invested, and build business cases for new facilities or upgrades.
- Rely on UNFC-based project classifications and case studies to de-risk investment discussions with regulators, investors and technology providers, showing that CRM recovery projects meet environmental, social and economic viability criteria.

Industrial supply chains (OEMs, recyclers, material users):

- For **OEMs and downstream users**, feed FutuRaM's scenarios into procurement and design strategies: e.g. anticipating future secondary supply, designing products for disassembly and CRM recovery, or planning offtake agreements for recycled CRMs.

- For **recyclers and processing industries**, use the dataset to benchmark available CRM-rich waste streams, decide where to site plants, and align investments with CRMA Strategic Projects and future IAA procurement rules favouring EU-origin, low-carbon materials.

After the Critical Raw Materials Act and the first European Strategic Projects, what role can FutuRaM play, also in light of the recent Industrial Accelerator Act?

The CRMA is now in force and sets **quantitative benchmarks**, establishes "**Strategic Projects**" across the value chain, and obliges Member States and operators to improve recovery of CRMs from waste, especially in sections dealing with **extractive and manufacturing waste**.

FutuRaM positions itself, in its own CRMA commentary, as providing the **knowledge base** and **UNFC-aligned tools needed** to (i) identify which waste streams and projects should be prioritised and (ii) supply high-quality data to support the designation and monitoring of Strategic Projects, notably in **Article 27** and related provisions.

The proposed **Industrial Accelerator Act (IAA)** seeks to rebuild Europe's industrial base and requires specific minimum shares of low-carbon, often EU-origin, materials in public projects (e.g. low-carbon steel, aluminium, cement), directly increasing demand for reliable EU secondary material streams. In this context, FutuRaM can: Help quantify how much of this demand could credibly be met from EU secondary sources and under what timelines, strengthening the case for linking IAA implementation to circular-economy and CRM-recovery investments. Provide evidence to integrate raw-materials considerations (including CRM recovery from WEEE, batteries and construction waste) into IAA-driven industrial planning and into future updates of both CRMA and related product/waste legislation.

In other words, **FutuRaM is an enabling layer**: it translates the high-level ambitions of CRMA and IAA into a map of where Europe's secondary CRMs actually are, how fast they will become available, and which concrete projects should be pursued first.

UNITAR

WATCH THE VIDEO

“Invest in data quality for a more efficient recovery”

Giulia Iattoni, Assistant Programme Officer at the United Nations Institute for Training and Research (UNITAR): “Data show that significant volumes of critical raw materials are already present in waste flows and will increase further by 2050, but their actual recovery depends on political, infrastructural, and technological choices”

by **Daniele Di Stefano**

What is the difference between observed data, modelling estimates, and future scenarios in the results of the FutuRaM project?

In the FutuRaM project we have collected and harmonised observed data from official sources, such as Eurostat, national reports, scientific literature, and industrial data, integrating them with mathematical models to fill the information gap. The observed data describe the current state of WEEE flows and their content of critical raw materials. **The modelling estimates reconstruct or complete missing information** through coherent assumptions, weighted estimates, and mass balances, when possible later validated by industry experts. The future scenarios developed in FutuRaM (business-as-usual, recovery, and circularity) are not forecasts, but represent possible developments up to 2050 based on changes in collection systems, recycling technologies, and market dynamics, allowing an assessment of how these conditions influence the availability and recovery of critical raw materials from WEEE and the achievement of the targets.

What does it mean, in simple terms, to measure the availability of critical raw materials in WEEE?

Measuring the availability of critical raw materials in WEEE means quantifying the entire value chain of the waste: from the generation and collection of flows, to their composition in terms of critical materials and elements, and up to the treatment and recovery processes.

Not all the material present in products is actually recoverable, because t**he availability as a secondary resource is influenced** by several factors: some of it is not intercepted by collection systems, while some, although collected, is not technically or economically accessible with current recycling technologies, due to low concentrations or the complexity of components. **A significant portion of WEEE in Europe does not enter formal collection channels** compliant with the WEEE Directive, which reduces the potential for recovering the critical raw materials contained within.

FutuRaM therefore integrates data on composition, waste flows, and treatment processes to estimate how much material can be obtained as a secondary resource.

Why is it important to distinguish between materials contained in WEEE and materials that are actually recoverable?

It is crucial because the mere presence of a material in WEEE does not imply its actual recoverability. Recoverability depends on several enabling factors—or, conversely, barriers: product design, concentration and distribution of materials, available recycling technologies, economic feasibility, and collection and pre-treatment systems. Some materials already achieve high levels of recovery today thanks to favorable properties and well-established technologies. Others represent flows with growing strategic interest and recovery potential, linked to the evolution and market penetration of the products containing them and to existing treatment processes. Conversely, some materials remain difficult to recover due to their dispersion within products and current technological limits, and are recovered only in limited quantities or through processes still under development.

What is the main message that FutuRaM data convey to Europe today?

The message of FutuRaM is that WEEE, along with other types of waste analyzed in the project — including batteries, vehicles, construction and demolition waste, mining waste, industrial slags and ashes, and wind turbines — represents a strategic source of secondary raw materials for Europe. Data show that significant volumes of critical raw materials are already present in waste flows and will increase further by 2050, **but their actual recovery depends on political, infrastructural, and technological choices**.

It is therefore necessary to strengthen collection and recycling capacity, while also promoting prevention strategies. A key element is shifting from an assessment based primarily on economic feasibility to a **perspective that also includes environmental benefits, supply security, and reduced emissions** from primary production. Finally, it is essential to invest in data quality to guide political and industrial decisions that are truly effective.

ERION WEEE

WATCH THE VIDEO

"In collection, quantity is not enough"

Interview with Giorgio Arienti, Director General of Erion WEEE, on the results of the European FutuRaM project

by **Alessandro Coltré**

Giorgio Arienti, you are the General Manager of Erion WEEE, Italy's largest producer responsibility system for electrical and electronic equipment waste. Could you explain where the main value losses occur today in WEEE flows?

According to the results of the FutuRaM project, Europe generates over 12 million tonnes of WEEE each year, but only a portion is treated in a way that allows the recovery of critical and precious metals: only half of the WEEE generated undergoes adequate treatment, enabling the recovery of about 0.4 Mt of critical raw materials (2022 data). **The main value losses occur particularly in unsegregated or contaminated streams**, where critical materials (for example, those in batteries, printed circuit boards, and advanced electronic components) end up diluted within general metal fractions. In concrete terms, up to 70% of the potential recovery of precious and critical metals can be lost if proper technologies and processes are not applied. Furthermore, the lack of detailed data and standardized methodologies makes it difficult to identify where to act. A solution like the Urban Mine Platform developed by the FutuRaM project, however, allows the identification of so-called **"material hotspots" — waste streams with high concentrations of critical materials** that, if properly managed, can generate significant economic and industrial value.

Which counts more: collecting more WEEE or collecting it better, and what priority initiatives should be implemented on both fronts?

FutuRaM clearly shows that collecting more is not enough, because quantity without quality does not lead to efficient recovery of critical materials. Collecting more is certainly important, and for this it is necessary both to educate citizens about what WEEE are and why proper separate collection is essential, and to bring WEEE collection to high-traffic and frequently visited locations, such as offices, schools, and local supermarkets. Limiting WEEE collection to municipal recycling centers and EEE (Electrical and Electronic Equipment) stores does not significantly increase the amounts sent for proper treatment. At the same time, it is crucial to collect better: selecting streams, separating materials, and reducing contamination. In practice, batteries, printed circuit boards, and electronic boards must be treated separately to maximize recoverable value. Priority initiatives should focus on developing and implementing advanced separation technologies that allow critical metals to be extracted with maximum efficiency, alongside standardized processes for WEEE classification and tracking, which are essential for obtaining reliable data to support strategic decisions. Optimizing logistics is equally important, minimizing waste and losses throughout the entire value chain. Only by effectively combining quantity and quality in collection and treatment can we significantly increase the value recovered from WEEE and contribute concretely to the supply security of strategic raw materials in Europe.

Which product categories or components deserve the most attention today if the goal is to recover critical raw materials?

The FutuRaM project has shown that the waste streams richest in critical materials are WEEE containing lithium and NiMH batteries, printed circuit boards, and electronic boards (from which rare earths, copper, cobalt, nickel, and other precious metals can be recovered), LEDs and fluorescent lamps, and advanced components of household appliances such as electric motors, sensors, and microchips.

The data collected by the project through sampling of WEEE in different Member States indicate that approximately **10–15% of the weight of household and professional WEEE consists of critical or precious metals**, mainly concentrated in copper in cables, aluminum in casings, rare earths in magnets and fluorescent powders, and platinum-group metals in electronic boards and displays. In LED and fluorescent lamp streams, rare earths can represent up to 5% of the total content, a significant value considering the growing prevalence of these products. Meanwhile, electric motors and sensors in complex household appliances contain small but concentrated amounts of copper, nickel, and rare earths. Properly treating WEEE and recovering the critical raw materials present allows these products to be valorized, reduces dependence on external imports, and strengthens Europe's material sovereignty. In this way, **WEEE can be transformed from waste into strategic industrial resources**, contributing significantly to a more circular and sustainable economy.

What is still missing in Italy to retain more industrial value from WEEE? And what is needed at the European level to be ready for the challenge of "material sovereignty"?

In Italy, **there is still a lack of complete and standardized data, advanced recycling infrastructure, and integrated industrial processes**, which means that a large portion of the critical materials present in WEEE is either exported or lost, resulting in economic and technological losses. At the European level, the FutuRaM project highlights the importance of adopting common methodologies and standardized guidelines for WEEE classification and recovery, developing forecast scenarios up to 2050 to ensure the availability of critical and strategic raw materials, and strengthening coordination among Member States to optimize the collection, treatment, and recycling of waste streams with high concentrations of valuable materials. Only with these integrated measures will it be possible to successfully address the challenge of material sovereignty, retain industrial value, **and ensure Europe's strategic autonomy and economic sustainability.**

Critical raw materials are now one of the key nodes of the twin transitions — Europe’s ecological and digital transitions. Batteries, electric vehicles, photovoltaic panels, wind turbines, electronic equipment, and high-tech infrastructure require indispensable materials, yet they are exposed to supply risks, geographic concentration of sources, and global industrial competition. This Special Report by EconomiaCircolare.com originates from the need to shift the focus from traditional mines to “urban mines” — that is, waste streams, end-of-life products, components, and materials already present within the European economy, which can become a strategic source of secondary raw materials.

Edited by Daniele Di Stefano, Raffaele Lupoli, Alessandro Coltré

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