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Source: Ciacci, L., Werner, T., Vassura, I., & Passarini, F. (2018). Backlighting the European Indium Recycling Potentials. *Journal of Industrial Ecology*. Doi.org/10.1111/jiec.12744

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1. European Commission. 2017. *Study on the review of the list of critical raw materials. Final Report. Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs*. Luxembourg: European

2. The EC is funding several projects addressing both the substitution of indium (e.g. on Transparent Conductive Oxides applications) or its sustainable production via innovative extraction, processing and recycling technologies. These research and innovation programmes include H2020 projects – such as INREP and INFINITY – both of which focus on substitution of indium.Relevant LIFE projects include LIFE RECUMETAL, PHOTOLIFE and LIFE-PHOSTER.

European Commission

Science for Environment Policy

Recycling 'end of life' technologies provides sustainable supplies of scarce valuable metals such as indium

Indium, a unique metal, is in short supply worldwide and is not recycled at the end of its life (EoL). Indium is used in a wide range of technologies, causing regions across the world that are reliant on its import — such as Europe — to be concerned about security of supply. Primary sources of indium are thought to be sufficient for medium-term needs, but with growing demand comes growing concern over long-term supply. A new study has conducted a material flow analysis and examined secondary sources of indium within European 'urban mines' and in-use stocks (IUS) of indium products, identifying these as potential sources of 500 tonnes of indium — if it were recycled at EoL.

Indium has unique properties such as transparency and conductivity, leading to its use in liquid crystal display (LCD) panels, luminous emitting diode (LED) chips, and photovoltaics (PV), while its heat-resistant properties make the metal ideal for use in low-melting fuses in fire alarm systems, soldering alloys, and jewel manufacturing.

Current demand for indium calls for 600-800 tonnes per year — but this number is estimated to increase with growing market size by up to 10% per year. However, indium is a by-product of base-metal (common or inexpensive metals) mining at an abundance of only 20–350 parts per million — it is thus only found in low concentrations that do not warrant mining exclusively for indium. Replacement materials have been identified by industry and are adequate for purpose, but these too are largely in short supply.

At present some in-plant recycling does occur, but EoL indium is not recycled in Europe. The reasons for this are varied: indium recycling at end-of-life is hindered by ineffective collection and separation from waste and obsolete commodities due to the wide dispersion of indium in these products. Yet, the regulated management of EoL alloys is still driven by the recovery of major carrier metals, such as iron and copper — and the associated recycling routes are unable to recover indium. Ultimately, the crux of the issue lies in the economic feasibility of EoL technologies. Secondary indium supply is more costly than primary production, and this situation is likely to continue unless more economically viable recovery processes are developed. The European Commission includes indium in its list of most critical raw materials, suggesting that securing supplies is a priority[1,2].

In a new study, researchers developed a material flow model for indium flows and IUS in Europe from 2002–2015. The conservation of matter principle (a fundamental principle of physics that states that the amount of mass within a closed system cannot change) was applied to balance inflows and outflows across the metal's life cycle (i.e. mining, smelting and refining, fabrication and manufacturing, use, and EoL management). A variety of data sources were consulted, from market research data for all European countries to historical European refinery records, relying on expert advice when scarce data led to variability. Ultimately, top-down and bottom-up approaches were combined to estimate the amount of indium in domestic goods, by identifying the list of goods containing indium and gathering European production statistics to estimate the amount demanded by European manufacturers. The model accounted for indium flows in extra EU trades, and annual quantities of net traded indium.

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European Commission

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Recycling 'end of life' technologies provides sustainable supplies of scarce valuable metals such as indium *(continued)*

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The simulation of indium generated at EoL, as a result of annual flows into use and accounting for product lifetime, resulted in 62 tonnes of indium embedded in obsolete goods and EoL products in 2014. The net indium accumulated in IUS for 2014 alone amounted to seven tonnes. For the entire 2002–2015 period, the cumulative mass of indium sitting in European urban mines amounted to nearly 500 tonnes.

Future demand for indium was examined and is likely to increase, with a rising demand for sustainable energy and EU consumers choosing larger LCD screens to replace older, smaller screens potentially increasing demand for thin-film PV containing the metal.

The EC has several initiatives to enable secure access to raw materials, and to reach sustainable production — these include a method for assessing the criticality of raw materials based on consumption patterns, packages to support a transition to greener energy systems[3,4], and the use of a circular economy (CE) model[5]. If a CE approach was implemented for indium[6], the amount that could be recovered from EoL is greater than the amount needed by European manufacturers. However, in order to use these urban mines of indium, methods of EoL waste collection and product sorting would need be addressed. Waste electrical and electronic equipment contains indium within glass panels such as LCD. Some techniques to extract indium from crushed LCD screens have been investigated, but process yields need improving. In addition, alloys of solders contain an amount of indium that could potentially be recycled, but current recycling routes focus on carrier metals such as zinc and do not allow for indium recovery.

To unlock the development of technologies that are financially viable and environmentally sustainable for recycling indium, innovative ways of collecting and processing waste must be explored[7]. For example, the recovery of other metals, alongside indium, from waste via eco-friendly 'design for recycling' strategies, would mean that the environmental impacts of recycling would be split across multiple valuable recoverable metals, making their life cycle assessments less damaging. Steps to enable the recycling of indium would require co-operation between governments and industry, as well as research into methods of sustainable recycling.

3. *See:* Raw materials innovation for the circular economy: sustainable processing, reuse, recycling and recovery schemes. Sub topic 07b focuses on recycling of raw materials from end-of-life products.

4. European Commission. 2016. *Clean energy for all Europeans—Unlocking Europe's growth potential*: Press release. Brussels: European Commission.

5. See: *Circular Economy Package—Implementation of the circular economy action plan, topic 07b*: **Recycling of raw materials from end-of-life products**. European Commission. 2015a.

6. Securing access to critical raw materials such as indium is a priority – as demonstrated by several initiatives adopted by the EC – e.g. the implementation of the circular economy. Putting recycling at the core of elemental cycles would spotlight urban mines or in-use stock as relevant means to supply sustainable amounts of material with potentials for reducing primary material inputs.

7. The greatest recycling potentials for indium are connected with its use in glass coating applications (e.g. LCD) because of high market penetration rates and relatively high indium amounts per unit of product. The general management of obsolete LCD would consist of (1) collection; (2) dismantling (either manual or mechanical disassembly); (3) treatment of displays (e.g., crushing, pyrolysis); and (4) recovery of indium. Processes for indium separation and purification include techniques such as solvent extraction and liquid membrane separation.