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Grand Challenges in Metal Life Cycles

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Extraction technologies launch the life cycles of metals currently in use in modern society. Those life cycles have many stages, each potentially marked by material losses, import/export flows, and stockpiling. Without reasonably accurate information on all the flows and stocks in metal life cycles, issues such as by-product extraction, metal stocks in use, and scrap generation remain difficult to quantify, making estimates on future needs for primary metals more challenging.

From the life-cycle perspective, a grand challenge when considering societal needs and wants over the long term is the status of resource estimates. On a global scale, especially for metals other than the most widely used, we can do little better than set ultimately recoverable resource quantities to a small multiple of crustal abundance. This is clearly a shaky foundation on which to anticipate prospective metal production several decades into the future, but it is the best we have. Cannot we do better, and how might that be accomplished?

A second grand challenge is the quantification of in-use stocks of metals. In theory, this is given by the integral over time of metal production minus process losses minus discards. Only the production rates are known with reasonable accuracy, however, and again only for the major metals. How can this situation be improved?

A third grand challenge is quantifying end-of-life recycling rates for metals. The metals are contained in a wide variety of products used in industry and society, and the end-of-life "production", largely from "urban mines" is poorly tracked. Some metal uses are inherently dissipative, while for others satisfactory recovery techniques remain to be developed, so that flows out of use do not equate to metal available for reuse. A lack of data on discards and recycling impedes attempts at the quantification of recycled flows. This information deficiency needs to be improved, but it is unclear how such improvement could come about.

A final challenge relates to the occurrence of groups of minor metals in the ores of major "host" metals, and the varying levels of demand for the minor metal "companions". Zinc ores contain highly-valued indium, for example, but also the often undesired cadmium, while copper ores provide widely-used selenium as well as generally unwanted arsenic. Increased attention and information sharing could inspire initiatives to better utilize and/or stockpile these currently unwelcome by-products. How might such activities be stimulated?

All of these grand challenges could be better addressed if actors at each stage of metal life cycles were to realize the benefits of improved system-level quantification and analysis. Society's dependence on metals is very high, but detailed knowledge of all aspects of supply and demand now and in the past is quite limited. The result is an unsatisfactory basis for long-term thinking. The situation can only be improved by the collaborative efforts of actors at the life-cycle stage: geologists, industrialists, product designers, consumers, and recyclers. The key question remains: How can such efforts be stimulated, and by whom?