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International Resource Panel

Metal Stocks in Society

Scientific Synthesis




United Nations Environment Programme

Acknowledgements

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Preface

Economic development is deeply coupled with the use of metals. During the 20th century the variety of metal applications in society grew rapidly. In addition to mass applications such as steel in buildings and aluminium in planes, more and more different metals are in use for innovative technologies such as the use of the specialty metal indium in LCD screens.

Metals are present everywhere around us and are one of the major materials upon which our economies are built. In particular in emerging economies, but also in industrialized countries, the demand for metals is increasing.

Therefore, mining activities expand, potentially leading to growing environmental impacts. Recycling is a way to mitigate these impacts. We can call this "mining above ground" or "urban mining", and these activities are of increasing importance in generating raw materials.

The continued increase in the use of metals over the 20th century has led to a substantial shift in metal stocks from below ground to above ground in applications in society. Such a shift raises social, economic, and environmental issues that have to be addressed by quantifying the amount of metal stocks in society and their lifetimes. For instance, the average lifetime of copper in a building is 25 to 40 years; afterwards, the metal is ready for mining.

Comparison of the per capita stocks in industrialized countries with those in developing countries suggests that if the total world population were to enjoy the same levels of use as the industrialized countries, the amount of global in-use metal stocks required would be 3–9 times those existing at present.

This report, the first in a series of six, has been compiled by the Global Metals Flows Group of UNEP's Resource Panel. It provides reasonably detailed information on the in-use stocks for five metals, and sparse but potentially useful information for nineteen other metals.

Closing the information gaps about stocks in human society provides important information about the potential of metal recycling to supply future demand. The utilization of these growing metal stocks through recycling is expected to be an important source for metal supply in the future.

Prof. Thomas E. Graedel

Leader of the
Global Metal Flows Working Group

Preface

Metals are a core, centre-piece of the global, economy: Whether it be in the manufacture of buildings or cars to the booming production of mobile phone, computers and other electronic goods, metals have become increasingly important to commerce.

But metals are also part of the challenge society is facing in its transition to a low carbon, resource efficient 21st Green Economy.

Metals are a finite resource, whose management, consumption and production echo to the need to adopt a recycling economy. Metals also have impacts as a result of their mining, extraction and refining. Meanwhile some metals have, as a result of their use and disposal in products and processes, health implications and ones that impact on the wider environment.

Understanding, quantifying and estimating the ways metals flow through economies is part of the solution to better managing their impacts and their benefits. Indeed the International Panel for Sustainable Resource Management, hosted by UNEP and established in 2007, identified metals as a key area in terms of the 21st century sustainability challenge.

The Panel's Global Metal Flows Group has identified six, central assessment reports as needed to bring clarity and to promote action towards a sustainable metals economy: stocks in society, recycling rates, environmental impacts, geological stocks, future demand, and critical metals.

This, the first report in this area, focuses on the stocks of metals in society. It provides, from a global perspective, the best scientific information available on the quantity of metal stocks in the world.

In particular it provides authoritative estimates of metals currently in use and their lifetimes. This in turn allows evaluations on the amounts of metals that may re-enter the global and national economies allowing governments to make more intelligent and targeted decisions on metals management.

This is no easy task and here I would like to congratulate the Resource Panel and its experts and partners for bringing to governments, business and civil society a further and important piece in the sustainability jigsaw puzzle.

Metals encapsulate the 21st century challenge of realizing sustainable development: development that requires and requests a far more intelligent understanding and trajectory that reflects the needs of a planet of six billion people, moving to more than nine billion by 2050.

Achim Steiner

UN Under-Secretary General and
Executive Director UNEP

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Abbreviations and Acronyms

EC European Commission

EU-15 European Union with 15 member states

GIS Geographic Information System

MDC The more-developed countries (MDC): are Australia, Canada, the European Union EU15, Norway, Switzerland, Japan, New Zealand, and the United States

LDC The less-developed countries (LDC) consist of all countries except those in the "more-developed" category

USGS United States Geological Survey

Units

g Gram

kg Kilogram (10^3 grams)

Mg Megagram (10^6 grams)

Tg Teragram (10^{12} grams)

metric ton Megagram (10^6 grams)

Chemical Abbreviations

Ferrous Metals

Fe – Iron

Mn – Manganese

V – Vanadium

Nb – Niobium

Cr – Chromium

Ni – Nickel

Mo – Molybdenum

Si – Silicon

Bi – Bismuth

Non-Ferrous Metals

Al – Aluminium

Co – Cobalt

Cu – Copper

Pb – Lead

Mg – Magnesium

Sn – Tin

Ti – Titanium

Zn – Zinc

Precious Metals

Ag – Silver

Au – Gold

Pt – Platinum

Pd – Palladium

Rh – Rhodium

Os – Osmium

Ir – Iridium

Ru – Ruthenium

Specialty Metals

Sb – Antimony

As – Arsenic

Ba – Barium

Be – Beryllium

B – Boron

Cd – Cadmium

Cs – Cesium

Ga – Gallium

Ge – Germanium

Hf – Hafnium

In – Indium

Li – Lithium

Hg – Mercury

Re – Rhenium

Sc – Scandium

Se – Selenium

Sr – Strontium

Ta – Tantalum

Te – Tellurium

Tl – Thallium

W – Tungsten

Y – Yttrium

Zr – Zirconium

La – Lanthanum

Ce – Cerium

Pr – Praseodymium

Nd – Neodymium

Sm – Samarium

Eu – Europium

Gd – Gadolinium

Tb – Terbium

Dy – Dysprosium

Ho – Holmium

Er – Erbium

Tm – Thulium

Yb – Ytterbium

Lu – Lutetium

Steel Alloy Family

SS – Stainless Steel

ST – Steel

Executive Summary

The continued increase in the use of metals over the twentieth century has led to a substantial shift from geological resource base to metal stocks in society. Such a shift raises social, economic, and environmental issues that require quantifying the amount of stock of "metal capital" utilized by society. This report reviews the relevant literature on this topic. From a compilation of 54 studies, it is clear that a reasonably detailed picture of in-use stocks and in-use lifetimes exists for only five metals: aluminium, copper, iron, lead, and zinc, and in only two cases have spatial stock allocations been performed. Limited data suggest that per capita in-use stocks in more-developed countries typically exceed those in less-developed countries by factors of five to ten. Sparse but potentially useful in-use stock information exists for nineteen other metals. There is a little information on stocks in government repositories, and essentially none on stocks in "hibernation", in tailings repositories, in industrial stockpiles, or in landfills, nor on typical in-use lifetimes for almost the entire periodic table of the elements. Outflows from in-use stocks, potentially useful for determining future rates of reuse, can currently be reliably estimated only for aluminium, copper, iron, and lead.

This is the first of six reports on the stocks and flows of metals, the last of which will draw upon the first five to address criticality and policy options related to the sustainability of metals.

1. Nature's Non-Renewable, Non-Fuel Resources

Nature provides human society with a rich spectrum of starting materials. In practice, the metal minerals constitute the largest set of these resources – more than sixty different elements in all. Modern technology is totally dependent on perhaps four of them – the iron and manganese that (with minor amounts of other metals) form structural steels, the aluminium widely used in transportation, the lead used for storage batteries, and the copper that transmits power from the generator to the user. Cases nearly as strong could be made for perhaps four others – the chromium and nickel that (together with iron) form the stainless steels, the zinc that inhibits metal corrosion, and the tin that is essential to modern electronics.

In actuality, however, hardly any element can be eliminated from a list of those important to modern society and cutting-edge technology. Manufacturers of everything from computer chips to health care equipment routinely employ dozens of different elements, each carefully chosen because of a specific physical or chemical property. Some have just the right conductivity for a specific purpose, or the right melting point, or the right photon wavelength, or the right catalytic efficiency at high temperature. It is not generally realized, but modern technology makes use of virtually every gift of nature, and if it doesn't do so in some instances today, it probably will tomorrow.

A key question that relates to this very broad and intensive use of metals is whether society needs to be concerned about long-term supplies of any or many of them. This is a many-faceted question that cannot be answered quickly or unequivocally. To address it, the Global Metal Flows Group envisions a series of six reports, of which this is the first:

Report 1 – Metal Stocks in Society

Report 2a – Recycling Rates of Metals

Report 2b – Metal Recycling – Opportunities, Limits, Infrastructure

Report 3 – Environmental Risks and Challenges of Anthropogenic Metals Flows and Cycles

Report 4 – Future Demand Scenarios for Metals

Report 5 – Critical Metals and Metal Policy Options

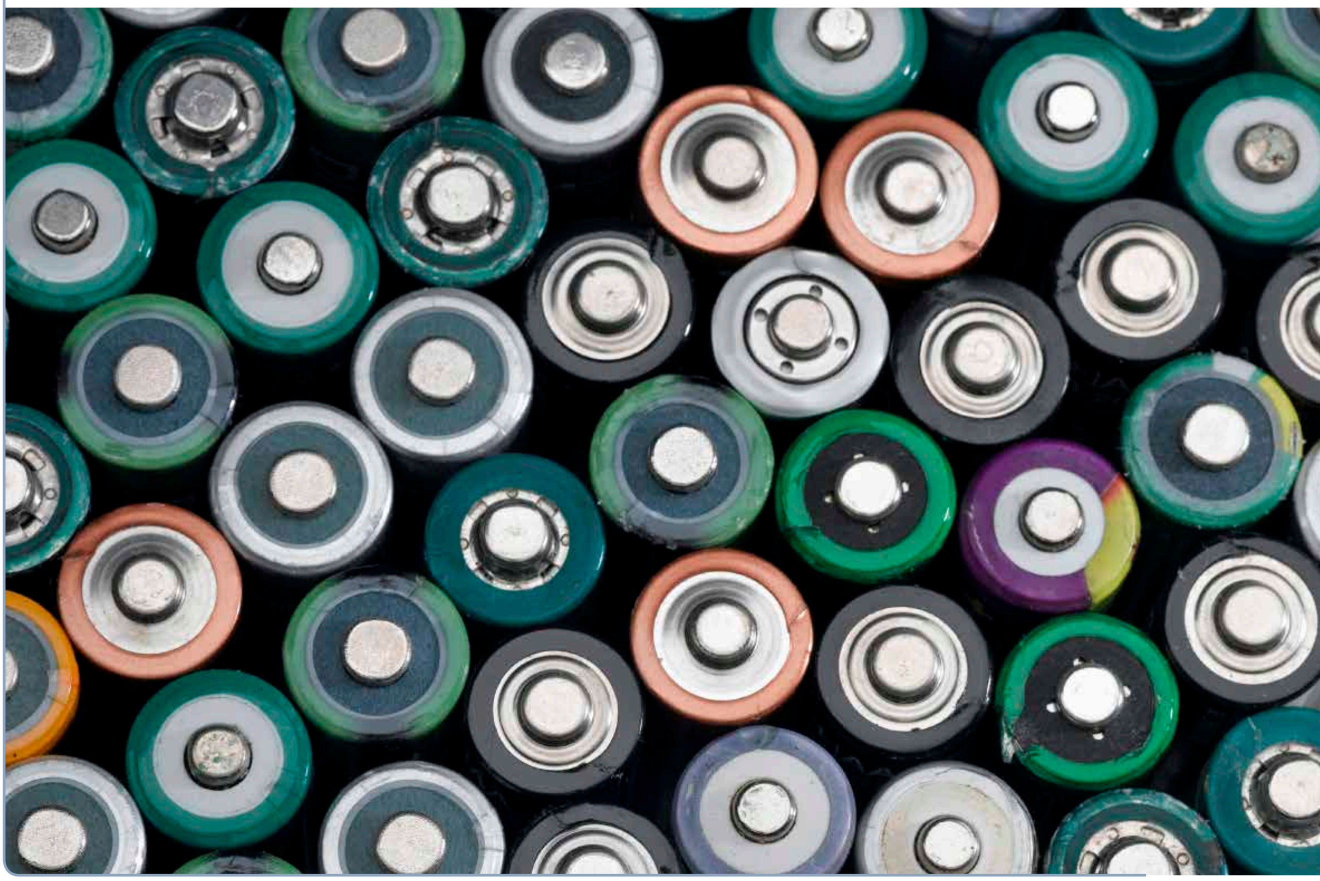
The first five reports form the necessary basis for the last report.

A number of policy-relevant issues will be addressed in these reports, including the following:

- To what extent is information available on the metal stocks in society? (Report 1)
- How well can scientists quantify the spatial distributions of metal stocks in society? (Report 1)
- What is the efficiency with regard to metal recovery? (Report 2)

- What are the recycling rates of metals in various countries, various regions, and the planet as a whole? (Report 2)
- What are the related environmental impacts of different metal mining refining and recycling techniques? (Report 3)
- To what extent is information available on the virgin reserves and resources of metals?
- To what extent can end of life discard streams from electronics, automobiles, and other products be used as a secondary source of metals? (Report 2b)
- What information is needed to develop realistic scenarios for potential metal stocks and rates of use in the future? (Report 4)
- How well can future rates of demand for metals be predicted? (Report 4)
- For which metals may supplies become critical, and over what time frames? (Report 5)
- Is today's use of metals sustainable? If not, what policy options are suggested by the information developed in Reports 1 – 4? (Report 5)

The first three of the six reports are in the current Terms of Reference and Work Plan for the Group, and are expected to be completed by 2010. The second three are expected to constitute the Work Plan for the Group for the 2010 – 2012 time period.



2. The Concept of Stocks

One aspect of the availability of metals concerns the natural (or virgin) stocks of metals: those deposited by geological processes in concentrations suitable for being extracted and processed, now and in the future. The total amounts of metals in such deposits are difficult to quantify accurately, but global estimates are publicly reported (e. g., USGS, 2008). This information is important to evaluations of resource sustainability, but is not the subject of this report and so is not treated further herein.

A group of less well studied stocks are termed "anthropogenic"; these are the metal stocks in society, already extracted, processed, put into use, currently providing service, or discarded or dissipated over time. These types of metal stocks in society can be appreciated with the help of the life-cycle diagram of Figure 1. Metal ores are mined from the ground, processed into the metal itself, fabricated into products, and then put into use. During processing, waste rock and impurities containing small amounts of the target metals are deposited in "tailings ponds". Some metal is held in stockpiles by processors, fabricators, and sometimes by governments. Eventually, the product is discarded, perhaps to recycling, perhaps lost to the environment. The metal in one form or another moves rapidly through most of these stages, but may stay in use for long periods – years, decades, perhaps a century or more. In some cases, such as metal in obsolete undersea cables, the metal is no longer in use, but not (yet?) recovered and recycled (Hashimoto et al., 2007). These "hibernating" stocks are potentially reusable, but their recovery may well not be economically feasible. All of these stocks are, in principle, the subject of the present report.

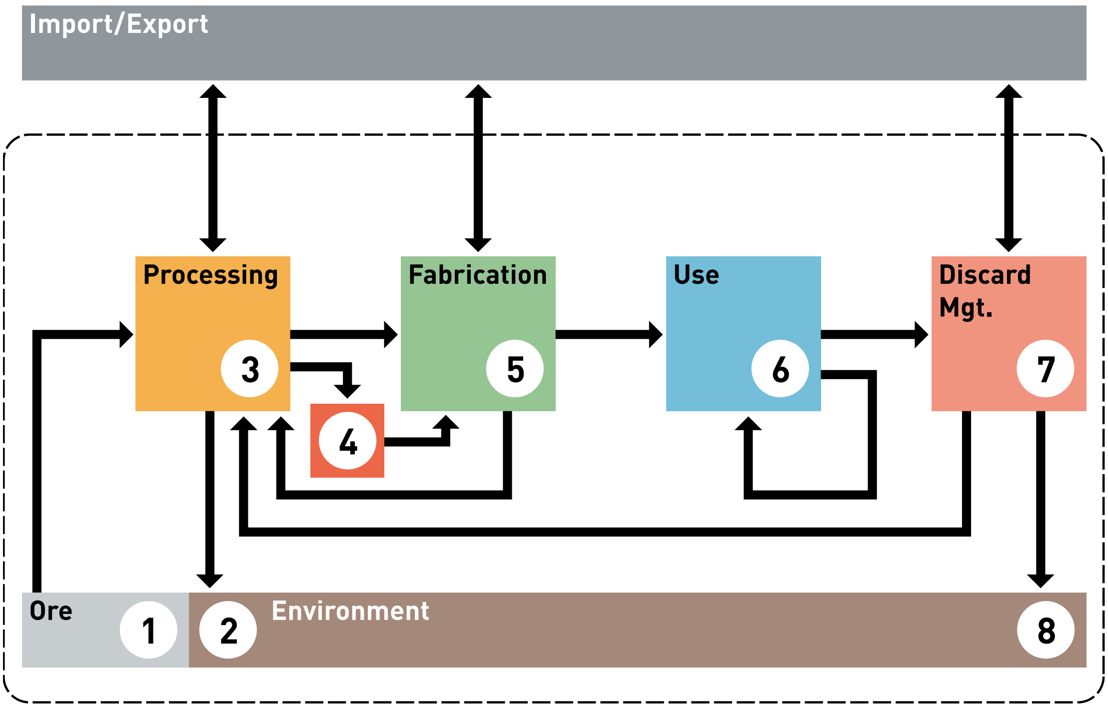


Figure 1.

The generic life cycle of a metal, with stock locations indicated:

1, metal in virgin ore bodies;

2, metal in tailings;

3, metal in processor stockpiles;

4, metal in government stockpiles;

5, metal in manufacturer stockpiles;

6, metal in-use stock;

7, metal in recycler stockpiles;

8, metal in landfill stockpiles.

Emissions from the Use stage are small, and not indicated here.

Material flow analysis characterizes and quantifies flows of materials into, out of, and through a system of interest, equating flows at each reservoir within the system by conservation of mass. In this analysis, the choice

of scale and level is critical (*scale* is "a spatial, temporal, quantitative, or analytic dimension used to measure or study a phenomenon" [Gibson et al., 2000], as with a ruler, *level* is a position along the scale.) The quantity of mass of a chosen material that exists within the system boundary of choice at a specific time is considered stock within the system. In terms of units of measurement, stock is a level variable (i. e., kg), while flow is a rate variable (i. e., kg per unit of time). In general, the metal stock in society is highest by far when material is in use (rather than in processing, fabrication, manufacturing, or waste management).

The metal portion of in-use stock can be defined in two ways. If an individual element is specified, in-use stock of metal refers to the total mass of that element, regardless of its chemical form. If a metal alloy is specified, in-use stock of metal refers to the total mass of that alloy (including all its constituent elements).

3. Methodology for Metal Stocks in Society

The definition of in-use stock is, as discussed previously, sensitive to the scale and level chosen. For reasons of relevance and data availability, most studies either explicitly or implicitly choose a time-scale of one year. System boundaries are typically interpreted to be spatial, and correspond to a pre-defined geopolitical or industrial sector boundary (e. g., industrial region, city, or country). Spatial boundaries are convenient from a data collection standpoint. They also allow for straightforward normalization of in-use stock estimates. Normalization by, for example, people or area within a system boundary is often desirable when comparing the relative states of different systems.

Once the appropriate time interval and spatial level have been chosen, the next step is to define an estimating procedure. This quantification is a considerable challenge, because there are no convenient, regularly-collected data that can be drawn upon. Instead, one of two complementary methods of estimation must be employed for the purpose (Brunner and Rechberger, 2004; Gerst and Graedel, 2008).

The first method is termed "top-down" anthropogenic stock estimation. Top-down estimations take information regarding flows, and infer metal stocks in society by computing the cumulative difference between inflow and outflow. Mathematically, if S_t is stock at time t, then in discrete time steps

$$S_t = \sum_{T_o}^{T} (Inflow_t - Outflow_t) + S_o$$

where T_o is the time of the initial time step, T is the current time step, and S_o is the extant stock at the initial time step. Typically, the range from T_o to T is 50 to 100 years, or longer. This yields the result that S_t is much larger than So, making the contribution of S_o negligible because of the general increase in metal stocks in society over the past several decades, and therefore generally unnecessary to include in practice.

In contrast, more recent top-down methods are utilizing increasingly complex methods. With the help of computing power and better access to data, contemporary top-down studies have been able to disaggregate metal production into inflow of specific final goods categories, and then model discard by defining lifetime functions for final product groups. While an improvement, this method is still completely dependent on inflow data, because historical outflow data is poor to nonexistent. Future efforts to collect historical data on outflows would allow for a well-needed empirical check on the results creating by discard models (see Ruhrberg (2006) for an example).

The types of available data have a significant effect on the system boundary defined for top-down analyses. Time steps are typically one year, because most applicable data are available as per year flows. The data used for inflow is gathered from government documents, technical literature, expert elicitation, and industry trade organizations. Usually, little discussion is spent on the relative reliability of these various sources. The appropriate spatial boundary is heavily dependent on the underlying data available, and as most inflow data are only collected at the country-level, this limits the scope of application. This can be problematic if higher spatial resolution is desired.

The "bottom-up" method takes an opposite strategy to top-down methods because it gathers information on stock variables to estimate in-use stock, and (if desired) infer the behaviour of flows. In its simplest form, estimating in-use stock via the bottom-up method is represented bywhere N_{it} is the quantity of final good i in-use at time t, m_{it} is

the metal content of in-use final product group I (see Appendix 1), and A is the number of different types of final goods.

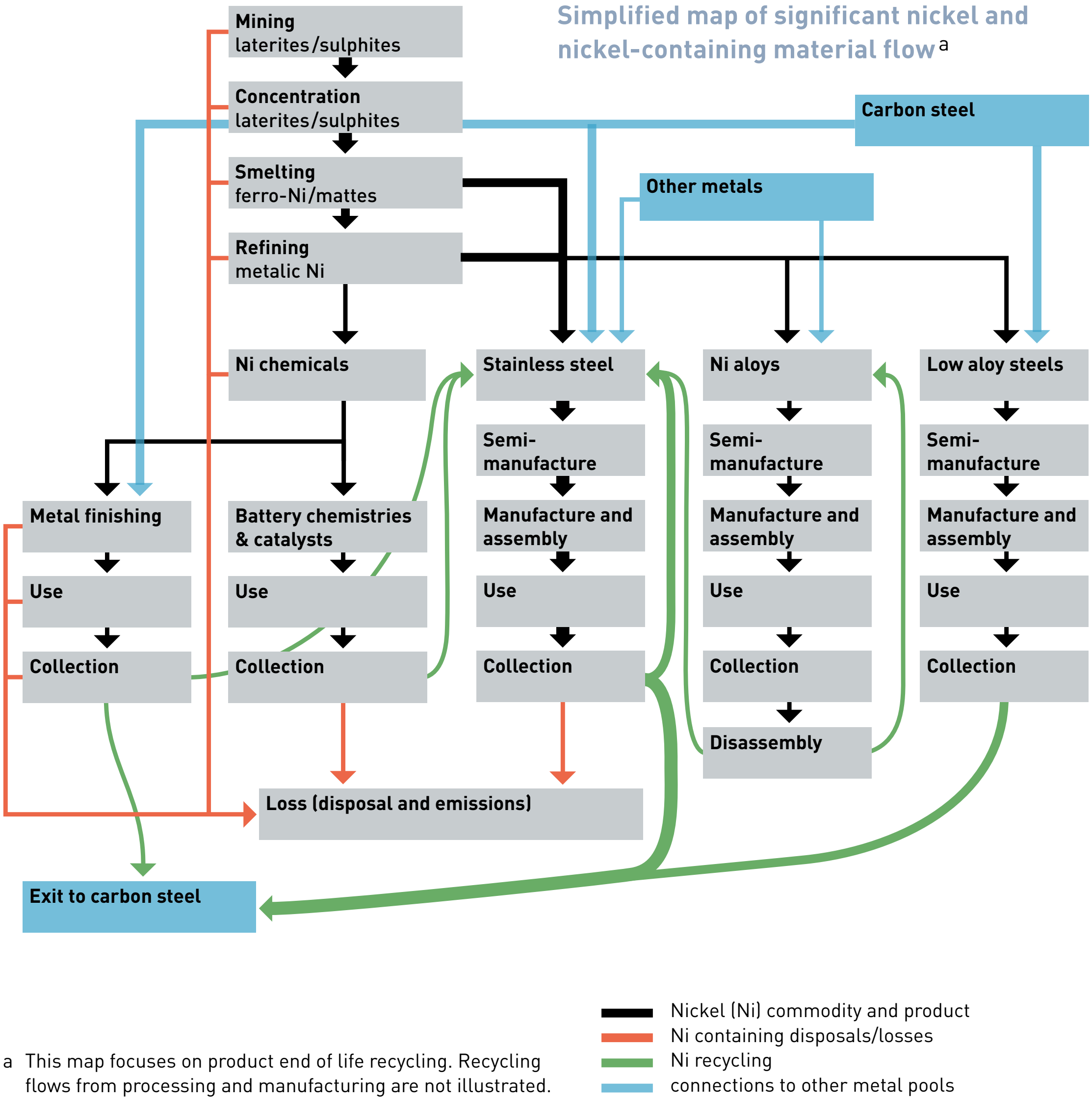
$$S_t = \sum_{i}^{A} N_{it} m_{it}$$

More complicated versions of the bottom-up method keep the same formulation of Equation 2, but allow for more precise definitions of the good categories and metal contents.

The types of available data also have a significant effect on the system boundaries of bottom-up approaches. As with the top-down method, most data collected are interpreted as being representative of a year time period. In this case though, the data are of stock existent during a year instead of the rate of flow per year. Also in similarity with the data collected for the top-down approach, data collected for the bottom-up approach are often constrained by geopolitical boundaries. However, this constraint is often not as strict for bottom-up methods, because stock-relevant (e. g., houses or cars) data are frequently available at the city/town or lower level of aggregation.

Figure 2.

The nickel recycling map (adapted from Dubreuil et al., 2009).



a This map focuses on product end of life recycling. Recycling flows from processing and manufacturing are not illustrated.

In these cases, where high spatial resolution and good count data for N_{it} are acquired, precision in determining metal content becomes the limitation. For many new final goods being input into use, such as machinery, electronics, and cars, metal content can be measured or obtained from manufacturers. Goods such as buildings are more difficult because they are less of a mass-produced commodity. However, using the metal content of new goods to infer the metal content of in-use stock can be problematic, because in-use stock contains an amalgam of stock vintages that have been accumulated over time. For example, applying the copper content of a newly built house to a house built in the 1950s would yield a misleading result. Alleviation of this data problem may prove to be difficult as it would require either a statistically significant regime of sampling of the metal content of in-use stock, or a significant historical investigation of engineering design plans for various goods.

Although both methods seek to measure the same quantity, they work in fundamentally different ways, and current datasets and technology are more appropriate for some goals than others. Inherent in the top-down method is evolution over time. As a result, that approach is often employed where inflow/outflow time series data are available. Because the top-down method is, to some extent, a more derived estimate of stock than the bottom-up method, it could be viewed as less precise. However, the bottom-up method is hindered by the inability to count everything in use, and from uncertainties as to the metal content of many of the units being included in the assessment. This trade-off must be considered in the context of the study goal. If a more detailed and spatially explicit analysis is desired, then the bottom-up method is likely to be more desirable. If less detail is acceptable, and larger temporal and spatial scale is the focus, then the top-down method may be the more appropriate method to employ.

Metals are rarely used in the pure form, but rather in alloys. From a thermodynamic point of view and from the economic perspective, it is not always feasible to "un-mix" the alloy to their metallic constituent. For noble metals (gold, platinum group metals, copper, lead for example), the recycling can produce the metal at high purity level. In contrast, nickel and chromium in stainless steel alloys will be recycled as stainless steel, but no nickel will be produced (see Figure 2). In order to report the stock of nickel, it is desirable to express stock as divided among the principal uses such as batteries & catalysts, low alloy steels, etc. Bottom-up studies are capable of doing this, and some of these studies are quite detailed in this regard (e.g., Rostkowski et al., 2007).

The above procedures do not apply to stocks of metals below the ground, either in virgin ores or in landfills. For the former, it is necessary to rely on information from test drillings supplemented and interpreted by geological theory. In the case of landfills, the data are so sparse that rough estimates are made based on calculations of discard of end-of-life products combined with information on the amount of recycled metal used over time.

4. A Review of Metal Stocks Determinations

4.1 In-Use Stocks

Given the definition of in-use stock and estimation methodologies, comparison of metal stock estimates from the literature can be made. A review of the scholarly literature, as well as industry publications and presentations, yielded a total of 54 studies of metal stocks in society from the peer-reviewed literature, published reports, and personal communications. The publication dates range from 1932 to 2007, with 70 % of those publications occurring after the year 2000. Twenty-four different metals (22 elements and 2 alloy groups) have been addressed, with a total of 124 metal stock in-use estimates, a few of which provide dynamic temporal information.

The individual data assembled in our review are presented in two Appendices: a specification of the principal final product categories (i. e., the sectors of principal use) in which each metal resides when in use (information necessary for bottom-up studies), and a listing of all the extant per-capita in-use stock determinations, by locale, applicable year, amount, and reference source. We content ourselves here with a presentation of a summary on a per capita basis and a discussion of the overall picture shown by the data. We also note that few of the papers deal with uncertainty in the data, despite the general impression that those uncertainties are large (see, for example, Hebrant and Sörme, 2001).

Table 1 lists the summarized in-use stock information for the major engineering metals. Copper, lead, zinc, and iron are the top four metals in terms of number of estimates in the study pool. Aluminium's stock in society is also fairly well characterized. There are several determinations for stainless steel,

Table 1. Extant In-Use Metal Stock Estimations for the Major Engineering Metals[a]

Zoom

Metal	Number of estimates	Percent of all estimates	Global per capita stock	MDC per capita stock[b]	LDC per capita stock[c]
Aluminum	9	7.4	80	350 – 500	35
Copper	34	27.0	35 – 55	140 – 300	30 – 40
Iron	13	10.7	2200	7000 – 14000	2000
Lead	20	16.4	8	20 – 150	1 – 4
Steel	1	0.8		7085	
Stainless steel	5	4.1		80 – 180	15
Zinc	14	11.5		80 – 200	20 – 40

a The years of the determinations in Tables 1 – 3 vary, but most are for the period 2000 – 2006. The units of per capita stock are kg of metal in most cases, but g of metal for cadmium, gold, mercury, palladium, platinum, rhodium, and silver. The total number of estimates is 124.

b The more-developed countries (MDC) used in this calculation are Australia, Canada, the European Union EU15, Norway, Switzerland, Japan, New Zealand, and the United States (altogether about 860 million people in 2005).

c The less-developed countries (LDC) used in this calculation consist of all countries except those in the "more-developed" category (altogether about 5620 million people in 2005).

and one for the aggregate of all types of steel (a mixture that is roughly 95 % iron). Geographically, an overwhelming majority of the estimates concern more-developed countries. On a global basis, top-down estimates for in-use stocks exist for only four of these elements: aluminium, copper, iron, and lead. The per capita stock of iron is largest, as befits its high rate of flow into use; aluminium's stock is slightly larger than that of copper, and that for lead is significantly lower. (Global values are generated by dividing total estimated in-use stock by global population. The results should not be interpreted as suggesting equivalent per capita in-use stocks around the world; most stocks clearly reside in more-developed countries.)

a bottom-up basis. The locales are diverse: Stockholm, Vienna, New Haven, Cape Town, Beijing, and Sydney. There are still too few bottom-up studies to evaluate the accuracy of this approach, although where comparisons of results can be made, they appear reasonable. At the city level, it is possible to allocate the stock on a spatial basis, and this has been done for Cape Town and Sydney.

Anthropogenic stock estimates exist for five precious metals, as shown in Table 2; most are for more developed countries. The exception is silver, for which a rather poorly documented global estimate exists.

Table 2.

Extant In-Use Metal Stock Estimations for Precious Metals.[a]

Metal	Number of estimates	Percent of all estimates	Global per capita stock	MDC per capita stock[b]	LDC per capita stock[c]
Gold	2	1.6		35 – 90	
Palladium	2	1.6		1 – 4	
Platinum	2	1.6		1 – 3	
Rhodium	1	0.8		0.2	
Silver	2	1.6	110	13	

a The years of the determinations in Tables 1 – 3 vary, but most are for the period 2000 – 2006. The units of per capita stock are kg of metal in most cases, but g of metal for cadmium, gold, mercury, palladium, platinum, rhodium, and silver. The total number of estimates is 124.

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c The less-developed countries (LDC) used in this calculation consist of all countries except those in the "more-developed" category (altogether about 5620 million people in 2005).

Few stock estimates are available on a regional basis - only aluminium for Europe, copper for North America and Europe, and stainless steel for several. The stock evaluations are all quite recent, and appear reasonably reliable. On a country basis, data exist for Japan, USA, Australia, and several European countries.

Urban-level evaluations have been performed for several metals and several cities, all on

For the "specialty metals" (those used in more modest quantities than the major engineering metals, particular for unique physical or chemical properties), Table 3 gives the anthropogenic stock estimates. Twelve different metals are listed, none with more than three determinations. The only global estimate in this group is for cadmium; it is seriously out of date and cannot be regarded with confidence. In a recent unpublished presentation, Halada (2008) described a top-down esti-

mate of in-use stocks for some 20 elements in Japan; he found that the Japanese in-use stocks of gold, indium, silver, tin, and tantalum were 10 – 20 % of estimated virgin reserves of those metals, indicating the importance of enhanced reserach efforts for these less-abundant metals.

For the more-developed countries, there is sufficient information in Table 1 to compute an average person's allocation of in-use metal stock. Doing so demonstrates the dependence of modern lifestyles on a substantial stock of metal, a perspective especially useful because few individuals are aware of their share of metals in infrastructures such as communications, rail networks, and power generation and distribution systems, as well as in their personal homes and vehicles. The average more-developed country citizen's in-use metal stock is between ten and fifteen metric tons. Of this amount, five metals – iron, aluminium, copper, zinc, and manganese, make up more than 98 %.

One feature of the limited data is that there appear to be significant differences at present in the per capita in-use stock of the more-developed and less-developed countries. Additionally, when measured at different spatial levels suburban residents appear to have larger per capita in-use stock than do urban or especially rural residents, although this is an observation that needs input from future research on in-use stock variations. Given the obvious wealth discrepancies, these results seem qualitatively reasonable, but much work remains to be done to better understand stocks from a spatial (or spatial analytical level) perspective. An additional factor is that taking into account an entire nation may increase the per capita in-use stock due to infrastructure and other in-use final goods that occur only in sparsely populated areas. Such final goods may include ships, large trucks, heavy industrial equipment, offshore drilling equipment, railways, military hardware, and aircraft.

Table 3. . Extant In-Use Metal Stock Estimations for Specialty Metals.[a]

Metal	Number of estimates	Percent of all estimates	Global per capita stock	MDC per capita stock[b]	LDC per capita stock[c]
Antimony	1	0.8		1	
Cadmium	3	2.5	40	80	
Chromium	3	2.5		7 – 50	
Cobalt	1	0.8		1	
Magnesium	1	0.8		5	
Manganese	1	0.8		100	
Mercury	1	0.8		10	
Molybdenum	1	0.8		3	
Nickel	3	2.5		2 – 4	
Tin	2	1.6		3	
Titanium	1	0.8		13	
Tungsten	1	0.8		1	

a/b/c see table 2

For perhaps only copper, iron, aluminium, and lead, and only for the more-developed countries, can we feel we have enough information to give us a reliable estimate of the stocks of metal in use. Nonetheless, the order of magnitude of in-use stocks, for those metals, at least, can readily be appreciated from the information assembled herein.

4.2 Stocks in Unmined Ores ("Resources" of Metals)

This subject will be addressed in a future report of the Global Metal Flows Group and is not discussed herein.

4.3 Stocks in Tailings

The metal contents of tailings are highly dependent on the efficiency of the separation process applied to the ore that was mined. Modern mines measure the metals concentrations in tailings discards, but the information is generally proprietary. We know of no stock estimates at levels higher than individual processing facilities.

4.4 Stocks in Processing Facilities

No general information is available on processor stockpiles. Most material moves rapidly through processing facilities, so the quantities in these stockpiles are probably relatively small.

4.5 Government Stockpiles

At least three governments, Japan, China, and the United States, are known to maintain stockpiles of selected metals. Those for Japan are reported to be completed by Y. Moriguchi. There is no official information on China's stockpiles, though some estimates are made (Shanghai Metal Corporation, 2008). Those for the United States are reported in USGS (2008 and preceding years).

4.6 Stocks in Manufacturing Facilities

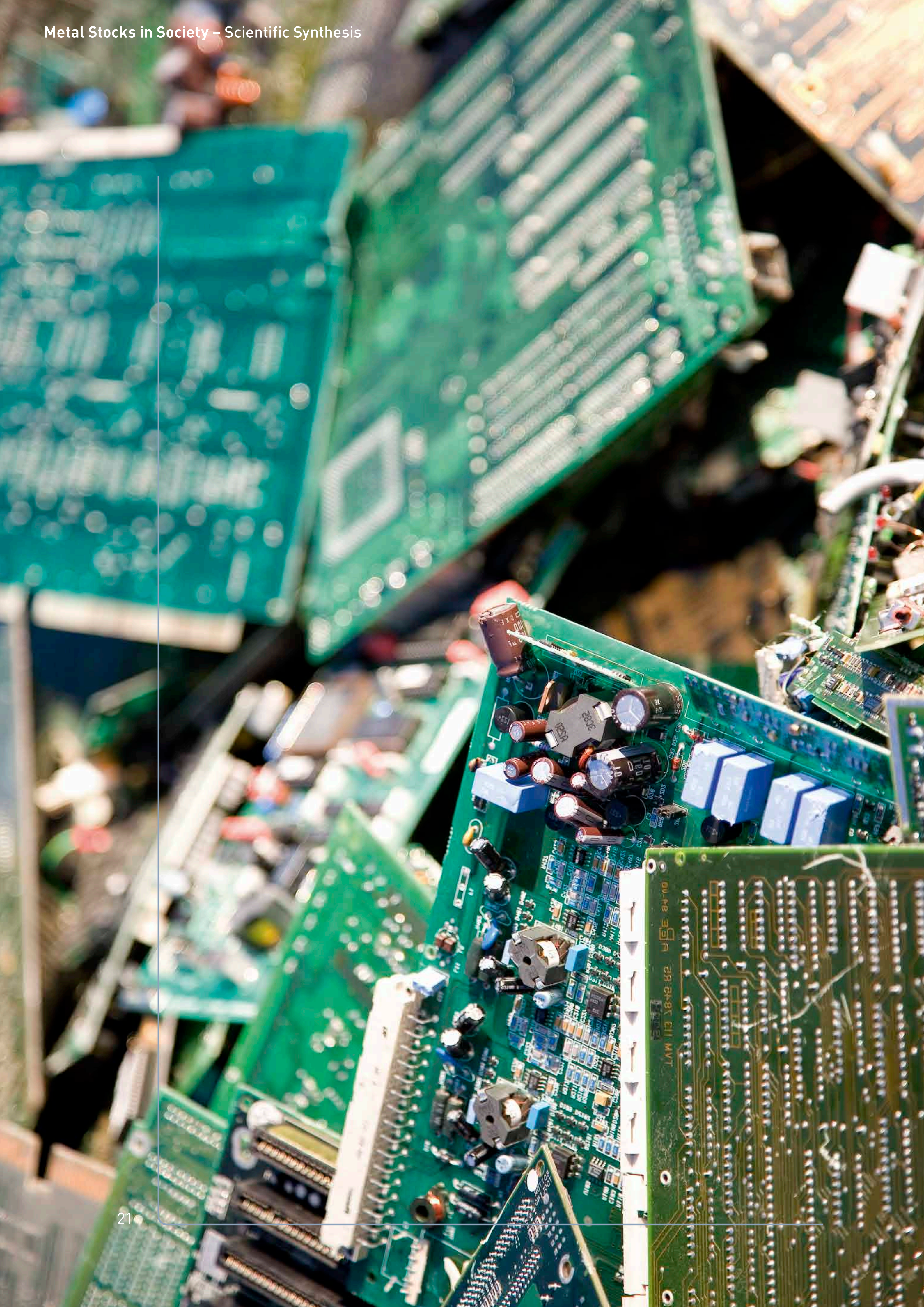
No general information is available on manufacturer stockpiles. Most material moves rapidly through processing facilities, so the quantities in these stockpiles are probably relatively small.

4.7 Stocks in Recycling Facilities

No general information is available on recycler stockpiles. Most material moves rapidly through processing facilities, so the quantities in these stockpiles are probably relatively small.

4.8 Landfill Stockpiles

Little information is available on the amount and location of metals in landfills. We are aware of only two estimates: for iron in U.S. landfills (850 Tg Fe; Müller et al., 2006), and for copper in global landfills (225 Tg Cu; Kapur, 2004). These amounts are relatively large, but the material in landfills is widely dispersed and resides in discarded products rather than ores. There are no instances of any significance where metal has been recovered from landfill stocks. In the case of materials whose use is increasingly regulated (e. g., mercury and cadmium), the landfill stock may, over time, exceed the stock in use.



5. Outflows from In-Use Stocks

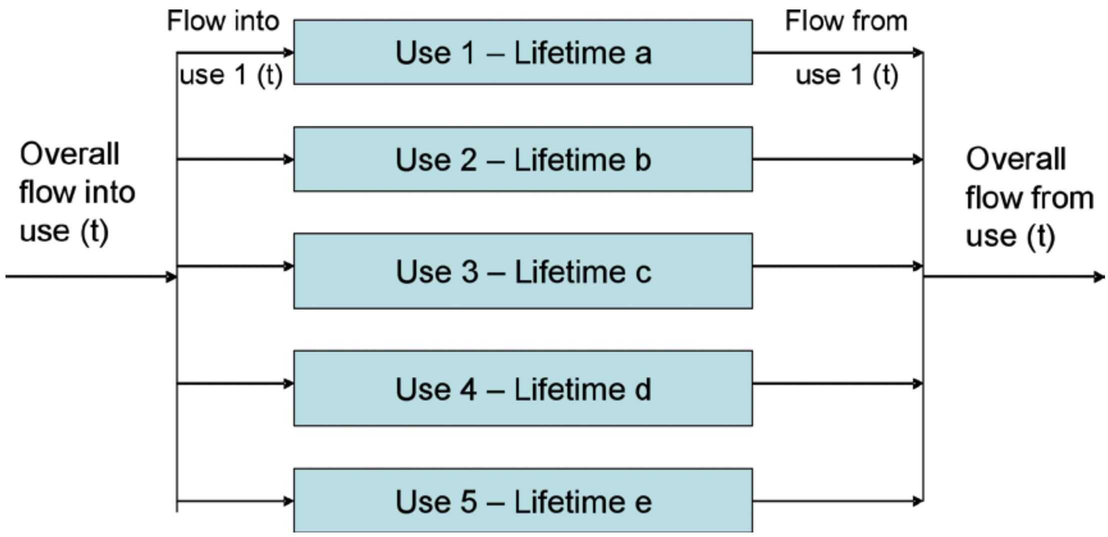


Figure 3.

A schematic diagram of the methodology for calculating outflows from in-use stocks.

Outflows (if recycled) from in-use stock represent a resource that decreases the requirements for mining of virgin material (as well as the associated environmental consequences). Although the amount of outflow (the "secondary material") that is supplied to smelters and refiners is generally measured, the outflow itself is not, so must be computed.

The outflow computation requires dynamic information on inflows over a number of years, plus estimates of the fractions of that flow entering each of the major uses, plus estimates of the average lifetimes of those uses, as shown in Figure 3.

It is important to mention that the potential recyclability of the several individual outflows can be quite different. For example, the recovery efficiency of copper from infrastructure is much more efficient than from electronics. In the recycling report of this working group (to be completed), these issues will be addressed in some detail. In most uses, some metal is lost to the environment by processes such as dissipation or corrosion. The amounts are quite small relative to other flows, however (e. g., Wang et al., 2007; Mao et al., 2008), and can be neglected for purposes of assessing metal stocks in society.

6. Potential Users of In-Use Stock Information

Mining Industries. The mining industries extract and concentrate minerals. Their operations often produce a number of by-product metals as a result of mineral associations in the ore. The interest of this sector is primarily in the sustainability of metal markets and in the future demand for virgin metals, a demand that is enhanced by increasing per capita resource intensity throughout the world and reduced by recycled scrap that can substitute for virgin metal. Perspectives potentially useful to these industries include metal in-use stock estimates to measure the stock of metal required to deliver any given service to a population, and the creation of scenarios of potential metal demand based on different assumptions of technology choice, population growth, and other relevant parameters such as the substitution for certain major uses of the metal by other metals or manmade materials (as in the substitution of copper electrical wire by aluminium wire). The paucity of in-use stock estimates, a lack of metal demand scenarios, and the absence of stock discard scenarios have to date prevented these industries from utilizing in-use stock information in these ways. All these considerations apply as well to countries for which mining is an important part of the national economy, especially if the mines are under governmental control.

Metal Production Industries. These industries produce metal from either ore or recycled scrap into metal of desired purity. They could benefit from scenarios of discards from stock in use, especially if the form of the metal (alloy, coated metal, etc.) were part of the scenario. Current in-use stock studies provide the basis for scenario development, but the analyses remain to be done.

Waste Management and Scrap Industries. The primary function of the waste management and scrap industries is to recover metals and minimize their loss to the environment. The factors determining which path a metal might take include the concentration and speciation of metal in discarded goods, the ease of separation and concentration, and by what manner the metal is discarded (separated or mixed). Thus, waste management and scrap industries have as their basic inputs materials which are spatially-heterogeneous and that embody a significant amount of uncertainty with regard to material content and timing of discard. Here, in-use stock information in itself is not of value here, but discard scenarios linked to in-use stock with relatively high temporal and spatial resolution could be.

Public Health and Environmental Agencies. Unlike the potential users discussed above, who are concerned with the quantity and form of metals recovered at discard, these agencies are concerned with the quantity and form of metals that are discarded or dissipated and not recovered. As with the waste management industries, they would value discard scenarios with high spatial resolution, in order to predict effects on public health and/or the environment.

Public Policy Organizations. These organizations are diverse, with many different goals. Economic and national security policy-makers are often concerned with having adequate scrap supply for certain metals in the case of disruption of trade in either metal commodities or final goods containing metals. Environmental policy-makers, at least in the context of resource efficiency, are concerned with promoting the environmental benefits of metal recycling, a goal that would be better enabled by discard data and/or scenarios with high spatial resolution.

7. Discussion and Challenges

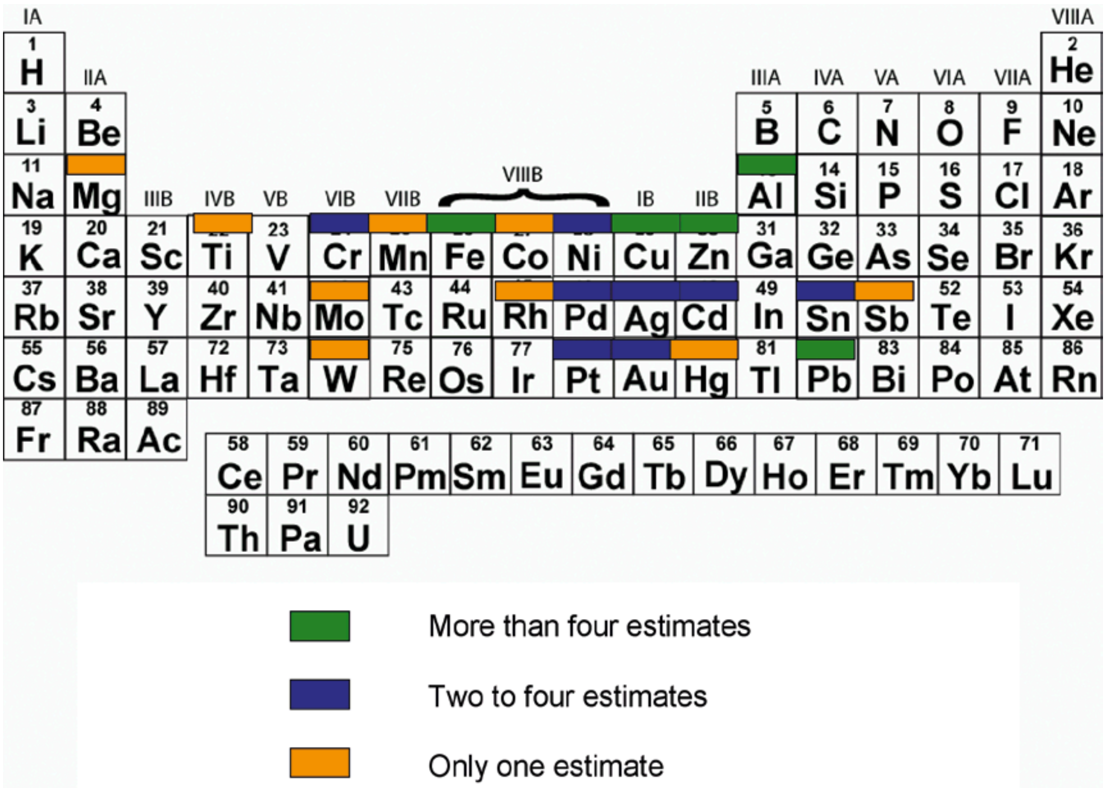


Figure 4. Information availability on in-use stocks of metals.

Anthropogenic metal stock estimation has the potential to address several interesting and pertinent questions concerning the future of metal use in society and associated environmental impacts, such as:

- Patterns in the way different societies or nations use, accumulate, and discard metal that is relevant to investigating future demand scenario
- The comparative quality and amount of metal in natural and anthropogenic stocks, and the potential of this information to inform discussions large-scale mining of cities?
- Ways in which the scale of environmental impacts from dissipative uses (corrosion, wear, etc.) change with increasing population growth and affluence?
- Scrap generation rate predictions (national, regional, global), and the virgin material demand offset that this scrap would provide
- Stimulating the development of effective public policy to increase collection and recovery.

Given the very wide spectrum of metal use in modern technology, it is noteworthy that for only about a third of the metals do we have any metal stock in society information at all, and for perhaps only five or six do we know enough to feel relatively comfortable with the quantification (Figure 4). Additionally, it is rare to nonexistent that any dynamic information is available; most stock estimates are no more than "snapshots in time". Dynamic stock information has the potential to reveal much useful information about the evolution of resource use, and should be actively pursued (see, for example, Månsson et al., 2009).

There are what seem to be obvious gaps in the information available for materials used in large quantities. For example, there appears to exist no global estimate for zinc stocks in society. Neither are there global stock estimates for the major alloying metals chromium, manganese, nickel, and tin, and only a few at country level for these metals. The stocks of magnesium, a light metal seeing increasing use in reduced-weight vehicles, have been evaluated only in Japan. For uranium and zirconium, necessary elements for nuclear power, there are no extant stock estimates at all.

Anthropogenic stock estimates of the specialty metals are almost nonexistent. This situation is partly due to lack of data, partly to lack of interest in such studies in the past few decades. One might target for attention the lanthanides (separately or as a group), which see extensive use in electronics and medical equipment, and indium, an element essential at present for flat-panel displays, and one perceived to be under supply pressure as it is only available as a byproduct of zinc ore processing (Fraunhofer Institute for Systems and Innovation Research, 2009).

Another obvious area of need is anthropogenic stock studies focused on less-developed countries. The gaps between the stocks of those countries and those of more-developed countries have much to tell us about potential future demands for resources, but little effort is underway to fill those knowledge gaps.

Quantification of metal stocks in society is limited by the availability of data in most cases. Information on flows into use is generally better than on flows out of use. Were governments to routinely collect discard, recycling, and waste data, in-use stock estimates could be significantly improved.

It is notable that very few studies of in-use stocks make any attempt to discuss or estimate uncertainty. Unlike laboratory systems where uncertainty can be rather precisely determined, in-use stock uncertainty is related to such factors as the average lifetimes of different products groups and the elemental compositions of buildings and equipment, which have significant but poorly determined variability. Some researchers (e. g., Rostkowski et al., 2007) have discussed potential sources of error in these studies. It is thought that recent stock estimates are accurate to perhaps +/- 25 %, and such accuracies are perfectly adequate bases on which to base public policy.

An avenue of research yet to be extensively explored is that of spatially-explicit in-use stock estimation. van Beers and Graedel (2007) have shown in a bottom-up study that relatively fine spatial resolution can be obtained through the utilization of GIS and spatially-explicit stock and population data. A recent study by Terakado et al. (2009) attempted to estimate the spatial distribution of the in-use stock of copper in Japan by utilization of nocturnal light images from satellite. This appears to be the first effort to exploit the combination of GIS and remote sensing for inferring in-use metal stock. Such work could be advantageous, as the results could be linked with other spatial attributes useful to decision makers.

It is worth noting that a variety of spatial boundaries have been the subject of anthropogenic stock studies, and one could ask what makes the choice of a city or any other geopolitical border appropriate for a stock study? The answer depends on the problem for which the in-use stock estimate is to be used. If one seeks to create a map of in-use stock for the purpose of providing insight into future scrap flows, then a geopolitical or any other sort of spatial boundary seems appropriate. Similarly, city boundaries are useful in employing in-use stock studies to estimate dissipative outflows (e. g., Sörme and Lagerkvist, 2002; McKenzie et al., 2009) However, if one seeks to infer conclusions about population affluence via in-use stock, a system that (such as city borders) is too small might be inappropriate for some metals. For example, a small spatial boundary might be appropriate for a metal which is mostly con-

tained in residential buildings, but not for metals which have significant stocks in infrastructure or manufacturing equipment that could be outside of the city border. Even if a spatial boundary as large as a country is chosen, stocks in a different country or continent, such as manufacturing equipment, could still be thought of as being used by the population in the system boundary. The same is true of metal in potentially mineable tailings. The answer could be to consider these as "hidden" stocks, much as the concept of hidden flows has been developed in the material flow analysis literature (Adriaanse et al., 1997).

All of the gaps discussed above are unlikely to be filled very soon unless more researchers become involved and unless more financial support for their efforts is forthcoming. At present, nearly all the anthropogenic stocks research is occurring in one small group each in Japan and the USA, and occasional efforts by groups in Europe. The scale of the need clearly outweighs the resources and staff currently striving to fill that need.

All potential applications of in-use stock information can benefit from significant improvements in the science of producing in-use stock estimates. First, the overall methodology would benefit from a blending of the top-down and bottom-up methods, incorporating the detail of bottom-up methods with the temporal aspect of top-down methods. (Only one study that compares results of both methods in a specific location (China in 2005; Wang et al., 2009) is known to us. It is encouraging that the methods give very similar results.) Second, the regional specificity must increase. A large majority of the studies reviewed are from developed countries, whose values are not representative of developing countries. Third, spatial resolution and greater disaggregation of final goods categories will become increasingly important for some end-users. And fourth, a common focus for future research is a more directed approach to quantifying and communicating uncertainty and validation of results. These four research foci have the potential to concentrate research time and resources where they will make the highest impact.

8. Conclusions

This report brings together the extant information on stocks of metals in society. In some cases, a good deal of consistency is shown to exist. In other cases, it is clear that the stocks have yet to be well characterized. A review of potential users makes it clear that in-use stock information by itself has limited utility. It is when this information is used to generate scenarios of future use intensity, discard, and reuse, with good spatial and temporal resolution and final good disaggregation, that its value is manifest. Such data and scenarios are now beginning to appear. In providing perspective and relative magnitudes, the results here thus are of inherent use as they stand, but they point as well to a large challenge ahead – to do a better job of evaluating stocks and their rates of growth and decay, and to use that information to make informed inferences about the future. Only by so doing can a fully adequate picture be created of the rich "anthropogenic mines" that have the potential to be tapped as sources of metal for the uses of modern society.

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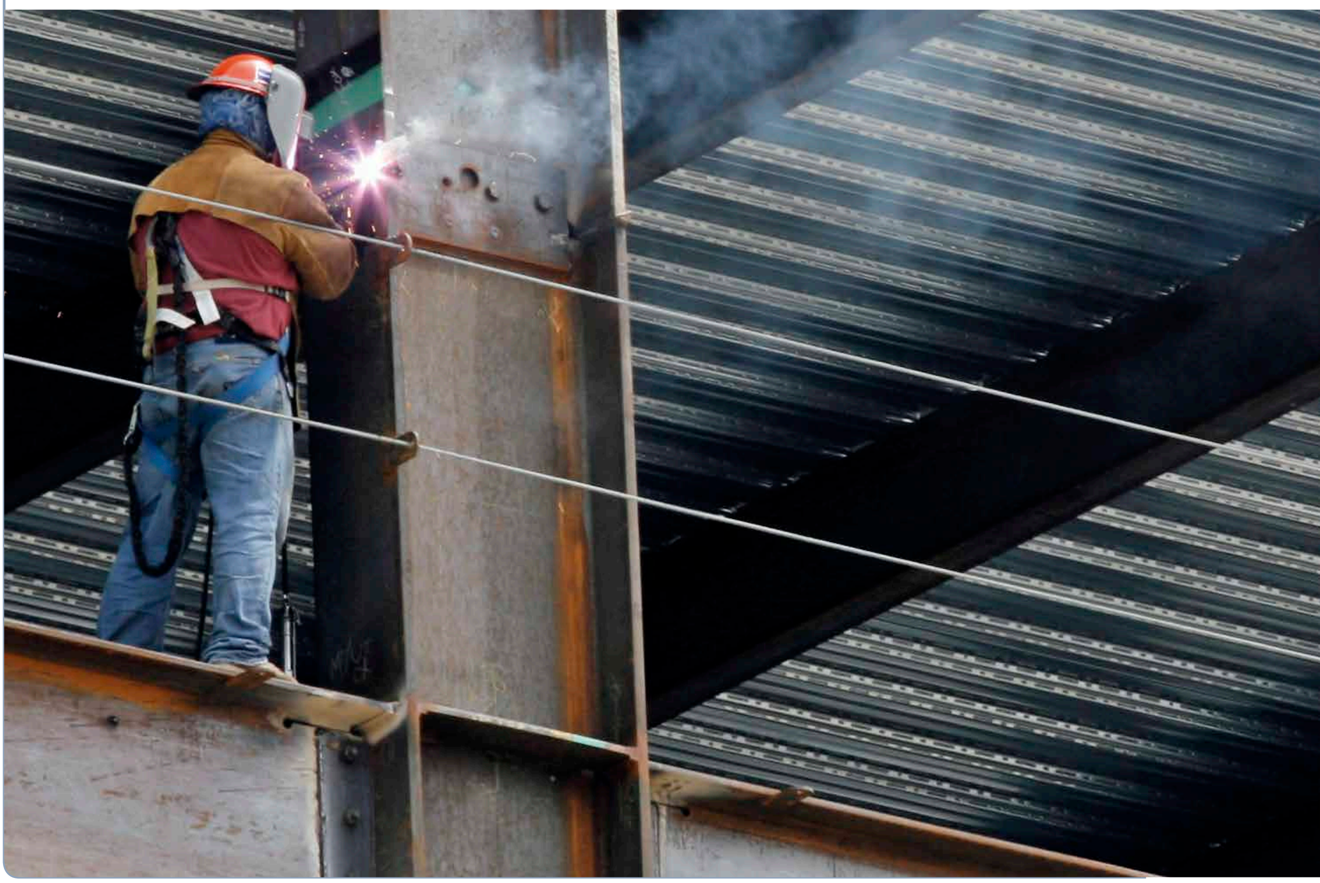

Appendices

The Appendices for this paper consists of two tables. The first provides background information for each metal in the study. The headings of these tables are defined as follows:

Metal: Scientific abbreviation of element (except for steel and stainless steel, which are denoted by ST and SS, respectively)

Reservoir: A category which groups a collection of related final goods in which a metal resides in-use.

Predominant final goods: Major final goods within a reservoir category.

End-use fraction: As of 2006, the weight percentage of metal produced that is an inflow for each reservoir. Percentages refer to specific metal. For example, the 25% listed for aluminum that will be used for building and construction means that 25% of aluminum inflow will go into building and construction.

Estimated residence time: Amount of time (in years) that a metal will remain in stock before being discarded. Values are taken from the literature. In the case where a value could not be obtained, a dash is used.

The second table provides information on each in-use stock estimate collected from the literature.

Appendix 1.

Specification of Prinicpal Metal Reservoirs.

Metal	Reservoir	Predominant Metal-containing Final Goods	End-use Fraction (percent)	Refer-ence	Estimat-ed Resi-dence Time (years)	Refer-ence
Al	Building & construction	Siding, window frames	25 %	(1)	30 – 50	(2, 3)
Al	Infrastructure	Cable used by power utilities	18 %	(1)	30 – 40	(2, 3)
Al	Transporta-tion	Automotive equip-ment, railway equip-ment, aviation	28 %	(1)	15 – 40	(2, 3)
Al	Packaging	Beverage cans, foil	13 %	(1)	0.3 – 0.8	(2, 3)
Al	Other		16 %	(1)	10 – 15	(2, 3)
Sb	Building & construction	Flame retardants	55 %	(4)	—	
Sb	Transporta-tion	Automotive equip-ment, railway equip-ment, ship building, aviation	18 %	(4)	10 – 30	(5)
Sb	Building & construction	Flame retardants	55 %	(4)	—	
Sb	Transporta-tion	Automotive equip-ment, railway equip-ment, ship building, aviation	18 %	(4)	10 – 30	(5)
Sb	Chemicals		10 %	(4)	—	
Sb	Business du-rables	Ceramics and glass	7 %	(4)	—	
Sb	Other		10 %	(4)	—	
Cd	Consumer and business durables	Batteries	81 %	(4)	3	(6)
Cd	Pigments	Business and con-sumer applications	10 %	(4)	—	
Cd	Industrial du-rables	Coatings and plat-ings	7 %	(4)	—	
Cd	Other		2 %	(4)	—	

Metal	Reservoir	Predominant Metal-containing Final Goods	End-use Fraction (percent)	Reference	Estimated Residence Time (years)	Reference
Cr	Building & infrastructure	Elevators, railways	25 %	(7)	30 – 50	(8)
Cr	Transportation	Automotive exhaust systems, railway equipment, ship building, aviation	15 %	(7)	30 for planes, trains, and ships	5-15 for automobiles and parts
Cr	Household appliances & electronics	Appliances, household products	5 %	(7)	15	(10)
Cr	Metal goods & other uses	Cutlery, fasteners	30 %	(7)	5 – 15	(10)
Cr	Industrial machinery	Heat exchangers, tanks	25 %	(7)	20	(8)
Co	Transportation	Automotive equipment, railway equipment, ship building, aviation	43 %	(4)	20 – 40	(8)
Co	Chemicals		26 %	(4)	—	
Co	Cutting tools	Blades, disks	22 %	(4)	1	(11)
Co	Industrial durables	Industrial (in-plant) machinery and equipment	22 %	(4)	20	(8)
Cu	Building & construction	Building wire and copper tube	50 %	(12)	25 – 40	(5)
Cu	Infrastructure	Copper cable used by telecom utilities and power utilities	22 %	(12)	50	(5)
Cu	Transportation	Automotive equipment, railway equipment, ship building, aviation	5 %	(12)	10 – 30	(5)

Metal	Reservoir	Predominant Metal-containing Final Goods	End-use Fraction (percent)	Reference	Estimated Residence Time (years)	Reference
Cu	Consumer durables	Appliances and extension cords, consumer electronics, fasteners and closures, household products	5 %	(12)	10	(5)
Cu	Business durables	Business electronics, lighting and wiring	10 %	(12)	20	(5)
Cu	Industrial durables	Industrial (in-plant) machinery and equipment	8 %	(12)	20	(5)
Au	Jewelry		85 %	(4)	30 – 50	
Au	Dental	Inlays	9 %	(4)	—	
Au	Electrical and electronics	Business electronics, consumer electronics	6 %	(4)	—	
Fe	Building & construction	Building beams, reinforcing bars	50 %	(8)	30 – 50	(8)
Fe	Transportation	Automotive equipment, railway equipment, ship building, aviation	20 %	(8)	20 – 40	(8)
Fe	Machinery and appliances	Appliances, industrial (in-plant) machinery and equipment	23 %	(8)	20	(8)
Fe	Other		7 %	(8)	25	(8)
Pb	Building & construction	Lead sheet	54 %	(6)	40 – 100	(6)
Pb	Machinery and appliances	SLI batteries	21 %	(6)	1 – 4	(6)
Pb	Machinery and appliances	Stationary batteries	14 %	(6)	8 – 12	(6)
Pb	Infrastructure	Lead pipe	11 %	(6)	20 – 50	(6)

Metal	Reservoir	Predominant Metal-containing Final Goods	End-use Fraction (percent)	Refer-ence	Estimat-ed Resi-dence Time (years)	Refer-ence
Mg	Castings	Transport systems, components	59 %	(4)	–	
Mg	Alloys	Packaging, transport	28 %	(4)	–	
Mn	Building & construction	Structural steel	29 %	(4)	30 – 40	(8)
Mn	Transporta-tion	High-strength steel	12 %	(4)	20 – 40	(8)
Mn	Industrial du-rables	Industrial (in-plant) machinery and equipment	12 %	(4)	25	(8)
Hg	Chlor-alkali production		40 %	(13)	–	
Hg	Manufactured products	Dental amalgams, instruments, lighting	32 %	(13)	–	
Hg	Artisanal gold		3 %	(13)	–	
Mo	Steel alloys	Stainless steel, su-peralloys	80 %	(14)	–	
Mo	Catalysts		8 %	(14)	–	
Ni	Building & construction	Alloys	9 %	(4)	30 – 50	(10)
Ni	Infrastructure		11 %	(4)	30 – 50	(8)
Ni	Transporta-tion	Automotive equip-ment, railway equip-ment, ship building, aviation	33 %	(4)	10 – 30	(10)
Ni	Consumer durables	Appliances, con-sumer electronics, household products	13 %	(4)	10 – 15	(10)
Ni	Industrial du-rables	Industrial (in-plant) machinery and equipment	25 %	(4)	20	(10)
Pd	Transporta-tion	Automotive equip-ment	57 %	(15)	20 – 40	

Metal	Reservoir	Predominant Metal-containing Final Goods	End-use Fraction (percent)	Refer-ence	Estimat-ed Resi-dence Time (years)	Refer-ence
Pd	Consumer durables	Consumer electron-ics, business elec-tronics	18 %	[15]	5 – 10	
Pd	Dental		14 %	[15]	—	
Pt	Transporta-tion	Automotive equip-ment	39 %	[15]	20 – 40	
Pt	Jewelry		37 %	[15]	20	
Pt	Chemical cat-alysts	Fuel cells	5 %	[15]	25	
Pt	Electronics	Consumer and busi-ness equipment	6 %	[15]	25	
Rh	Transporta-tion	Automotive equip-ment	86 %	[15]	20 – 40	
Rh	Glass manu-facture		6 %	[15]	—	
Rh	Chemical cat-alysts	Fuel cells	6 %	[15]	—	
Ag	Industrial ap-plications	Electronics	Solders	Other	44	20
Ag	Jewelry, ta-bleware		29 %	[16]	20 – 40	
Ag	Photography	Film, plates	22 %	[16]	20 – 40	
Ag	Coins and medals		5 %	[16]	10 – 40	
SS	Transporta-tion	Automotive, rail, ship	29 %	[17]	10 – 30	[10]
SS	Industrial machinery		20 %	[17]	20	[10]
SS	Building & construction		18 %	[17]	30 – 50	[10]
SS	Electronics		7 %	[17]	10	[10]
SS	Other		26 %	[17]	15	[10]

Metal	Reservoir	Predominant Metal-containing Final Goods	End-use Fraction (percent)	Reference	Estimated Residence Time (years)	Reference
Sn	Cans and containers		27 %	(4)	—	
Sn	Electrical and electronics		23 %	(4)	—	
Sn	Construction	Corrosion prevention	10 %	(4)	30 – 50	(8)
Sn	Transport	Corrosion prevention, solder	10 %	(4)	20 – 40	(5)
Ti	Carbides, chemicals, metal and metal alloys		3 %	(4)	—	
W	Cutting tools		50 %	(11)	1	(11)
W	Lighting		22 %	(11)	—	
Zn	Building & construction	Galvanised steel (e.g., frames, piping), zinc alloys (e.g., brass appliances), and pure zinc (e.g., roofing)	48 %	(18)	10 – 50	(5, 8)
Zn	Transportation	Motor vehicles, vehicle tires, and railway transport, sea and air transport	36 %	(18)	2-20	(5, 8)
Zn	Business durables	Machinery	7 %	(18)	—	
Zn	Chemicals		5 %	(18)	—	

Appendix 2.

Per capita in-use stock estimates.

Metal	Locale	Year	In-use Stock	Per Capita Mass Unit	Refer-ence
Al	World	1947	2.2	kg	(19)
Al	World	2002	79	kg	(20)
Al	World	2003	82	kg	(2)
Al	Europe	2004	199	kg	(1)
Al	UK	1968	52	kg	(21)
Al	Japan	2000	343	kg	(22)
Al	USA	2000	483	kg	(23)
Al	China	2005	37	kg	(24)
Al	Connecticut, USA	2006	361	kg	(25)
Sb	Japan	2000	1.0	kg	(22)
Cd	World	1985	41	g	(26)
Cd	Steiermark, Austria	2003	320	g	(27)
Cd	Stockholm, Sweden	1995	79	g	(28)
Cr	Japan	2000	54	kg	(22)
Cr	Stockholm, Sweden	1995	8	kg	(28)
Cr	New Haven, USA	2005	7.1	kg	(29)
Co	Japan	2000	0.8	kg	(22)
Cu	World	1929	17	kg	(30)
Cu	World	1947	19	kg	(19)
Cu	World	1960	25	kg	(31)
Cu	World	1994	55	kg	(32)
Cu	World	1998	35	kg	(33)
Cu	World	2000	50	kg	(34)
Cu	North America	1999	170	kg	(5)
Cu	Western Europe	1999	190	kg	(35)
Cu	USA	1932	73	kg	(36)
Cu	USA	1948	139	kg	(37)
Cu	USA	1957	161	kg	(38)

Metal	Locale	Year	In-use Stock	Per Capita Mass Unit	Refer-ence
Cu	USA	1960	164	kg	(31)
Cu	USA	1961	166	kg	(39)
Cu	USA	1979	216	kg	(40)
Cu	USA	1990	270	kg	(33)
Cu	USA	1990	294	kg	(41)
Cu	Sweden	1998	140	kg	(42)
Cu	USA	1998	253	kg	(43)
Cu	USA	1999	238	kg	(44)
Cu	Japan	2000	298	kg	(22)
Cu	Switzerland	2000	220	kg	(45)
Cu	USA	2000	391	kg	(23)
Cu	Australia	2002	275	kg	(46)
Cu	USA	2003	175	kg	(47)
Cu	Australian territories	2002	245-295	kg	(46)
Cu	Steiermark, Austria	2003	156	kg	(27)
Cu	Connecticut, USA	2006	157	kg	(48)
Cu	Stockholm, Sweden	1995	170	kg	(28)
Cu	Stockholm, Sweden	1995	140	kg	(49)
Cu	Cape Town, South Africa	2000	36	kg	(50)
Cu	Sydney Metropolitan Area, Australia	2002	255	kg	(46)
Cu	Sydney city center, Australia	2002	605	kg	(46)
Cu	Beijing city center, China	2004	30	kg	(51)
Cu	New Haven, USA	2005	144	kg	(52)
Au	Japan	2000	35	g	(22)
Au	USA	2000	92	g	(23)
Fe	World	1985	2.1	Mg	(26)
Fe	USA	1950	15	Mg	(53)
Fe	Japan	2000	11.3	Mg	(22)

Metal	Locale	Year	In-use Stock	Per Capita Mass Unit	Refer-ence
Fe	USA	2000	14.2	Mg	[23]
Fe	China	2004	1.5	Mg	[54]
Fe	USA	2004	11-12	Mg	[8]
Fe	Steiermark, Austria	2003	10	Mg	[27]
Fe	Urban China	2004	2.7	Mg	[54]
Fe	Rural China	2004	0.64	Mg	[54]
Fe	Connecticut, USA	2006	9.3	Mg	[55]
Fe	Kitikyushu, Japan	1995	7.3	Mg	[56]
Fe	Beijing, China	2000	2.3	Mg	[57]
Fe	New Haven, USA	2005	8.8	Mg	[52]
Pb	World	1947	19	kg	[19]
Pb	World	2000	8	kg	[6]
Pb	Africa	2000	3.9	kg	[6]
Pb	Asia	2000	3.7	kg	[6]
Pb	Commonwealth of Independent States	2000	4	kg	[6]
Pb	European Union	2000	41	kg	[6]
Pb	USA	1948	7	kg	[37]
Pb	USA	1957	14	kg	[38]
Pb	USA	1961	15	kg	[39]
Pb	Netherlands	1998	115	kg	[58]
Pb	France	2000	31	kg	[6]
Pb	India	2000	0.8	kg	[6]
Pb	Italy	2000	32	kg	[6]
Pb	Japan	2000	15	kg	[6]
Pb	Japan	2000	25	kg	[22]
Pb	United Kingdom	2000	78	kg	[6]
Pb	USA	2000	40	kg	[6]
Pb	USA	2000	146	kg	[23]

Metal	Locale	Year	In-use Stock	Per Capita Mass Unit	Refer-ence
Pb	Stockholm, Sweden	1995	73	kg	[28]
Pb	Vienna, Austria	1991	120-210	kg	[59]
Mg	Japan	2000	5.2	kg	[22]
Mn	Japan	2000	99	kg	[22]
Hg	Stockholm, Sweden	1995	10	g	[28]
Mo	Japan	2000	3.1	kg	[22]
Ni	World	1947	0.2	kg	[19]
Ni	Stockholm, Sweden	1995	4	kg	[28]
Ni	New Haven, USA	2005	2	kg	[60]
Pd	Japan	2000	4	g	[22]
Pd	Germany	2001	1.3	g	[61]
Pt	Japan	2000	3.2	g	[22]
Pt	Germany	2001	1.5	g	[61]
Rh	Germany	2001	0.15	g	[61]
Ag	World	1991	110	g	[62]
Ag	Japan	2000	13	g	[22]
SS	Europe Union 15	2000	95	kg	[10]
SS	China	2000	15	kg	[10]
SS	Japan	2000	178	kg	[10]
SS	Russia	2000	138	kg	[10]
SS	USA	2000	80	kg	[10]
ST	Japan	2000	7.1	Mg	[63]
Sn	World	1947	0.4	kg	[19]
Sn	Japan	2000	3.2	kg	[22]
Ti	Japan	2000	13	kg	[22]
W	USA	2000	0.8	kg	[11]
Zn	World	1947	6	kg	[19]
Zn	USA	1947	6.3	kg	[37]

Metal	Locale	Year	In-use Stock	Per Capita Mass Unit	Refer-ence
Zn	USA	1957	15	kg	(38)
Zn	USA	1961	16	kg	(39)
Zn	USA	1990	92	kg	(64)
Zn	Japan	2000	76	kg	(22)
Zn	USA	2000	210	kg	(23)
Zn	Australia	2002	205	kg	(46)
Zn	Australian territories	2002	190-220	kg	(46)
Zn	Steiermark, Austria	2003	89	kg	(27)
Zn	Stockholm, Sweden	1990	40	kg	(28)
Zn	Cape Town, South Africa	2002	18	kg	(65)
Zn	Sydney Metropolitan Area, Australia	2002	190	kg	(46)
Zn	Sydney city center, Australia	2002	420	kg	(46)

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65. van Beers, D.; Graedel, T. E., The Magnitude and Spatial Distribution of In-use Zinc Stocks in Cape Town, South Africa. African Journal of Environmental Assessment and Management 2004, 9, 18 – 36. Groupings of Metals

International Panel for Sustainable Resource Management

As our economies have grown, so has the use of materials and resources. In an increasingly globalised economy, the challenge for policy-makers is to streamline actions for ensuring a more sustainable management of resources, both renewable and non-renewable. There are existing measures such as policies on climate change and biodiversity that tackle certain aspects of the global resource issues. However a holistic approach to resources management is needed to better identify their interlinkages and gaps in a systemic way.

The establishment of UNEP's International Panel for Sustainable Resource Management, or Resource Panel for short, is a first step towards addressing this need. The Resource Panel was officially launched in November 2007 and aims to provide the scientific impetus for decoupling economic growth and resource use from environmental degradation.

The objectives of the Resource Panel are to provide independent, coherent and authoritative scientific assessments of policy relevance on the sustainable use of natural resources and in particular their environmental impacts over the full life cycle as well as to contribute to a better understanding of how to decouple economic growth from environmental degradation.

This work builds on and will contribute to other related international initiatives, including the development of the 10-year framework on sustainable consumption and production (Marrakech Process), the Green Economy Initiative and the Global Environment.

Global Metal Flows Working Group

Economic development is deeply coupled with the use of metals. The growing demand for metals implies a permanent pressure on the resource base. Metals are resources that have a high value and in principle can be easily reused and recycled. Reuse and recycling activities of metals on a global scale can contribute to closing the loops, turn waste into resources, and are expected to thereby reduce environmental impacts, safeguard the availability of metals, minimize metal prices, and promote meaningful and safe jobs for poor people in developing countries.

The Global Metal Flows Working Group aims at contributing to the promotion of reuse and recycling of metals and the establishment of an international sound material-cycle society by providing scientific and authoritative assessment studies on the global flows of metals. Expected results include revealing potentials for increasing the resource efficiency of metal flows at the national and international level.

About the UNEP Division of Technology, Industry and Economics

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The Division works to promote:

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> adequate management of chemicals,
> the integration of environmental costs in development policies.

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UNEP DTIE activities focus on raising awareness, improving the transfer of knowledge and information, fostering technological cooperation and partnerships, and implementing international conventions and agreements.

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A key question that relates to the very broad and intensive use of metals is whether society needs to be concerned about long-term supplies of any or many of them.

This is a many-faceted question that cannot be answered quickly or unequivocally. To address it, the Resource Panel's Working Group on Global Metal Flows envisions a series of six reports, of which this is the first one addressing metal stocks in society.

The continued increase in the use of metals over the twentieth century has led to a substantial shift from geological resource base to metal stocks in society. This report reviews the relevant literature on this topic. From a compilation of 54 studies, it is clear that a reasonably detailed picture of in-use stocks and in-use lifetimes exists for only five metals: aluminium, copper, iron, lead, and zinc. Limited data suggest that per capita in-use stocks in more-developed countries typically exceed those in less-developed countries by factors of five to ten.

Reliable data on metals stocks in society and their lifetimes are essential for building a global recycling infrastructure in the future.

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