Precious Materials Handbook

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Precious Materials Handbook

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Dr. Matthias Grehl

Materials based on metals and semiconductors are key contributors to the progress of technologies supporting today's sophisticated society. Although they form an integral part of our daily life, it is not always obvious to value their importance and the impact they have on the development of new applications. Indeed, in most cases these materials are hidden in tools, equipment, and devices or they contribute to the production of other products in a nearly invisible way as in the case of catalysts. They determine the performance of products including electronics, telecommunication equipment, cars and batteries through their unique and fundamental properties.

Materials are back in the spotlight. This is a consequence of the booming demand for equipment and devices, ever increasing requirements for better performance, coupled with economic growth and the rapid development of new markets and economies. New materials are needed and solutions are required to tackle the problem of scarcity. This is particularly the case for precious and special metals which are at the core of new technology developments but which are limited in supply. In combination, these two characteristics act as key drivers to increase our scientific knowledge of the materials' properties and of the technologies to produce them in economically and environmentally acceptable conditions. For this trend to more sustainable solutions to succeed will require fundamental scientific breakthroughs.

The objective of this book is to illustrate how metal-based materials contribute to crucial applications. Examples have been selected in line with specific mega-trends which have a tremendous bearing on society and the environment.

1. Resource scarcity: Metals are becoming more scarce. This is particularly the case for so-called technology metals that are often found only as a by-product of more common metals. Targeted efforts are needed to collect used devices and products and to recover the incorporated metals. At the same time, solutions have to be developed to use less critical materials to reach equivalent or even better functionality.

2. More stringent emission control standards: Today, increasing numbers of all types of cars, off road equipment, motorcycles, boats, etc. are burning huge amounts of fossil fuel. In doing so, they cause air contamination, which has to be reduced to acceptable levels. Legislation is therefore becoming tighter and exerts pressure on industries to come up with new solutions in collaboration with universities and research institutes.

3. Electrification of vehicles: This is also linked to the trend towards reduced emissions and resource scarcity. Taking into account the need for CO_2 emission reduction and limited availability of fossil fuel, manufacturers are developing new concepts such as hybrid and full-electrical vehicles in order to provide more efficient and less polluting mobility solutions. Such vehicles require many new materials technologies, not least of which are those for new-generation batteries.

4. Increase in renewable energy production is the key element in developing a more sustainable energy mix. More efficient and less polluting energy generation technologies are needed to cope with the increasing demand for energy, reflecting the growth of the world's population.

Major scientific tools supporting and accelerating the research and development efforts around the world have made tremendous progress during the last decade. A specific chapter on disciplines such as modern analytical tools, modelling and simulations, as well as knowledge and innovation management illustrates some of the new developments in this field.

We hope that you will enjoy reading this book and that it will contribute to the appreciation of the importance of metals and semiconductors. Many scientists and technology specialists are working with passion to enhance the performance of these materials and to improve the efficiency of the processes to produce them in the most sustainable ways.

We would like to thank all the contributors to this book who have taken the time to share their insights with us.

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AVAILABILITY OF METALS AND MATERIALS

Christian Hagelüken, Ralf Drieselmann, Kris Van den Broeck

Materials scientists have customarily assumed the routine availability of the entire suite of materials. As is the case with 'peak oil', this assumption is now being challenged, as shortages, episodic or more long-lived, become increasingly possible. As concerns rise, the analytical approaches and appropriate data sets needed to do more than raise the alarm become central items for investigation. At bottom, what is needed is a sound perspective on potential supplies of materials over the long term and an equally sound perspective on long term demand. Neither of those perspectives is addressed satisfactorily or comprehensively today.

Material demand depends, of course, on the quantity of as-yet-untapped virgin resources, the uses to which those resources may be put, the desirability of those uses for modern society, and the potential substitutes that exist for those uses. The potential for recycled material as an alternative to virgin material is of obvious relevance as well. Many of the necessary facts are well known for the major use metals—iron, copper, zinc, and the like. Much less information is available for the scarcer metals such as selenium, indium, or tellurium. Financial markets for these latter materials generally do not exist and, as a consequence, the materials tend to change ownership in private transactions not visible to most analysts. Information on materials management at end of product life is also sparse to nonexistent. These deficiencies render efforts to assess the availability of materials a real challenge, particularly for many of the materials that are most interesting and promising for modern technology.

Given that there is no simple source for materials availability information, a thorough understanding of the issues surrounding uses, markets, market drivers, and material stocks above and below ground is a necessary foundation for understanding the materials' potential to provide a better life over the long term. It is this foundation upon which technology will build its future because materials availability is a necessary prerequisite to materials use.

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Sustainable Use of Metals

Metals and minerals are classical examples of non-renewable resources, and their extraction from the Earth by mining of ores cannot be seen as sustainable in the strict sense of the word. Mining, by definition, depletes ore reserves. Through mineral processing and subsequent smelting and refining, ores are decomposed, and the desired substances (e. g., specific metals) are isolated. Other undesired ore constituents are changed fundamentally in their nature, deposited back into the environment as tailings or slag, fumed into the air, or dissolved into processing effluents.

However, if the focus is less on the ore in a certain, specific state and more on its metallic ingredients, and if the system boundaries are extended to their entire utilisation cycle, the picture changes somewhat. Metals are not lost or consumed (except those used in spaceships and sent into outer space); they are only transferred from one manifestation into another, moving within and between the lithosphere and the technosphere. Whether products and (production) wastes form a future source for metal extraction depends on physical parameters such as concentration, 'deposit' size, and accessibility as well as on social, technical, and economic parameters. In an ideal system, sustainable use of metals could indeed be achieved by avoiding spillage during each phase of the product life cycle (i.e., during mining, smelting, product use, and recycling/recovery of the metals).

Today, the reality differs significantly from this ideal state. Life cycle and recycling systems are far from optimal for many different metals; precious and special metals, in particular, are very susceptible to suboptimal life/utilization cycles. Depending on the metal, losses can vary between small and very large. As a result, a discussion about materials supply security has arisen anew for a number of metal resources, focusing on potential scarcities and the impacts of supply constraints (Gordon, 2006, p 1209 and Wolfensberger, 2008). Such a discussion requires quantitative information about metal reserves (ore bodies and end-of-life products) and flows. In addition, it is necessary to pinpoint where in the (supply) chain other factors (e. g., availability of specialist production and expertise rather than the material availability itself) cause the bottleneck (Morley, 2008). Furthermore, interactions and interdependencies between metal cycles and future needs and developments need to be included in the materials security discussion.

For some of these aspects, valid quantitative data for metals are available, such as geological reserves and resources (ore stock), mine production, demand by application and region. Less data are available about in-use stocks in durable products and infrastructure and these data rely heavily on assumptions concerning in-use losses, product lifetimes, and hibernating products. Data about potential metal stocks in waste deposits are rarely available. Modelling metal stocks and flows has made valuable contributions for a number of base metals (e. g., Bertram, 2002, p 43; Boin, 2005, p 26; Elshkaki, 2007 and Reck, 2008, p 3394), but little information is available about precious and special metals. A recent report (UNEP, 2010) published within the framework of the International Panel for Sustainable Resource Management compiles 54 studies on metal stocks in society. These studies reveal that the lack of data grows as the scope of the investigation shrinks. Data on the global or country level are relatively easy to come by, whereas much less data are available on the process level (including material efficiencies). Comprehensive models for the latter have been developed (Reuter, 2010, p 192 and Reuter, 2006, p 433). For the platinum group metals, a study on stocks and use patterns in Germany has been published (Hagelüken, 2005), covering all relevant application areas and providing detailed insights into individual products' lifecycles and fates as well as recycling rates at end-of-life. Reliable data on both macro-economic and micro-process levels are needed to predict and quantitatively assess what goes on in the life cycle, how high the losses are, and what optimization potential exists.

The biggest challenge lies in the end-of-life (EoL) phase of (metals in) products. There appears to be very little information on metal stocks in 'hibernation', in tailings repositories, in industrial stockpiles, or in landfills, likewise on typical useful lifetimes of products. Questions in this context include: How many EoL products enter into a recycling channel? Are discarded products accumulating in controlled/centralised locations, that could serve as future metal resources or are they being widely dispersed so that future recovery is unfeasible? How do (old) products move around the world, and what will be their fate at their final destinations? How effective is each recycling process and the combination of processes in a recycling chain? How can individual metals be effectively recovered from complex multi-metal assemblies in a product? What is the impact of product design/lifetime and social/societal factors on the above questions?

All of this put into one key question, we ask: How much of a metal is lost in each step along its entire metal/product life cycle now and in future, and how are these losses influenced by the social, economic, and technical factors present throughout the life cycle?

In the following, we will explore possible answers to this question and offer guidance to optimise life cycles and their subsystems in a sustainable manner. Emphasis will be put on the EoL phase as well as on losses that occur during primary production and manufacturing. To identify interdependencies and potential conflicts in a comprehensive system approach, we will use precious and special metals as examples for the following reasons.

- Precious and special metals are expensive and thus offer economic incentives for recycling. In areas where their recycling fails, structural limitations can more easily be identified than for metals where economic and technical constraints are mixed.

- Most of these 'minor metals' (defined in figure 1) are by-products from ores of a major or carrier metal. This has particular implications for interpreting reserves and mine production.

- Precious and special metals are widely used in complex, multi-metal products with often very low concentrations per metal. This implies significant technology challenges in recycling as minor metals are bound to each other and major metals, but in other ways than in ores.

- Precious and special metals' low concentration in ores and complex production processes imply significant environmental impacts of their primary supply (figure 1), making efficient recycling even more relevant.

- Most of these metals are used in 'clean-tech' or 'high-tech' products and have experienced tremendous growth rates in recent years. They are seen as a vital resource for the future and some of them are seen critically in terms of supply security. The expression 'technology metals' is increasingly used to underline their crucial functions.

EEE metals	Demand for EEE T/yr (2007)*	Emission T CO_2/T metal**	Total emission [MT]
Copper (Cu)	4,500,000	3.4	15.30
Cobalt (Co)	11,000	7.6	0.08
Tin (Sn)	90,000	16.1	1.45
Indium (In)	380	142	0.05
Silver (Ag)	6000	144	0.86
Gold (Au)	300	16,991	5.10
Palladium (Pd)	33	9380	0.31
Platinum (Pt)	13	13,954	0.18
Ruthenium (Ru)	27	13,954	0.38
TOTAL	4,607,753	–	23.71

* Authors' estimate based on various statistics (rounded)
** Ecoinvent 2.0, (ETH Zürich/EMPA)

1| CO_2 emissions from primary production of selected metals with high relevance for electrical and electronic equipment (EEE) (Hagelüken, 2010)

Neither of the terms 'technology metal' and 'minor metal' clearly define a distinct group of elements. 'Minor' can refer to metals that have relatively low volumes of production or use, that occur in low ore concentrations, that are regarded as rare, or that are not traded at major public exchanges (e. g., the London Metal Exchange). A further important feature is that most minors are geologically closely connected to certain major metal deposits, and thus their mining output depends heavily on the host metal. Such by-product or coupled product relations lead to highly complex demand/supply and price patterns. There are a few examples for minor metals that are extracted on their own (e. g., lithium, tantalum), but due to their specific properties and relatively low production volumes they are still included. Thus, to summarize, 'minor metals' is used in this chapter as a synonym for special metals and 'technology metals' serves as a wider term including the precious metals along with the special metals. By no means does the word minor refer to the metals' importance; on the contrary, they play a most significant role in sustainable technology solutions.

The Significance of Special and Precious Metals

Special and precious metals are of specific importance for clean technologies and other high technology equipment and so play a key role in modern industrial technologies. Information technology (IT), consumer electronics, as well as materials used in sustainable energy production such as solar cells, wind turbines, fuel cells, and batteries for hybrid cars are all important areas of application. These metals are crucial for improving the efficiency of energy production (in steam turbines), for reducing the environmental impact of transport (jet engines, car catalysts, particulate filters, sensors, control electronics), for improving process efficiency (catalysts, heat exchangers), and in medical and pharmaceutical applications. Figure 2 provides an overview of these main applications areas for each metal and illustrates their significance for modern life.

	Bi	Co	Ga	Ge	In	Li	REE	Re	Se	Si	Ta	Te	Ag	Au	Ir	Pd	Pt	Rh	Ru
Pharmaceuticals	major					major											major		major
Medical/dentistry		major	major	major	major			major	major		major	major	major	major		major	major		
Super alloys		major					major	major			major								major
Magnets		major					major		major			major							
Hard alloys		major									major								
Other alloys					major	major		major	major	major		major							
Metallurgical*	major					major			major										
Glass, ceramics, pigments**	major	major			major	major			major			major	major	minor		minor	major	major	
Photovoltaics			major	major	major				major	major		major	major						major
Batteries		major			minor	major	major						major						
Fuel cells						major								minor		minor	major	minor	major
Catalysts		major		major			major	major	major			major	major	major	major	major	major	major	major
Nuclear					major	major	major												
Solder	major				major								major						
Electronic	minor	major	major	major	major		major	major		major	major	major	major	major	minor	major	minor	minor	major
Opto-electric			major	major	major		major		major	major		major							
Grease, lubrication			major			major													

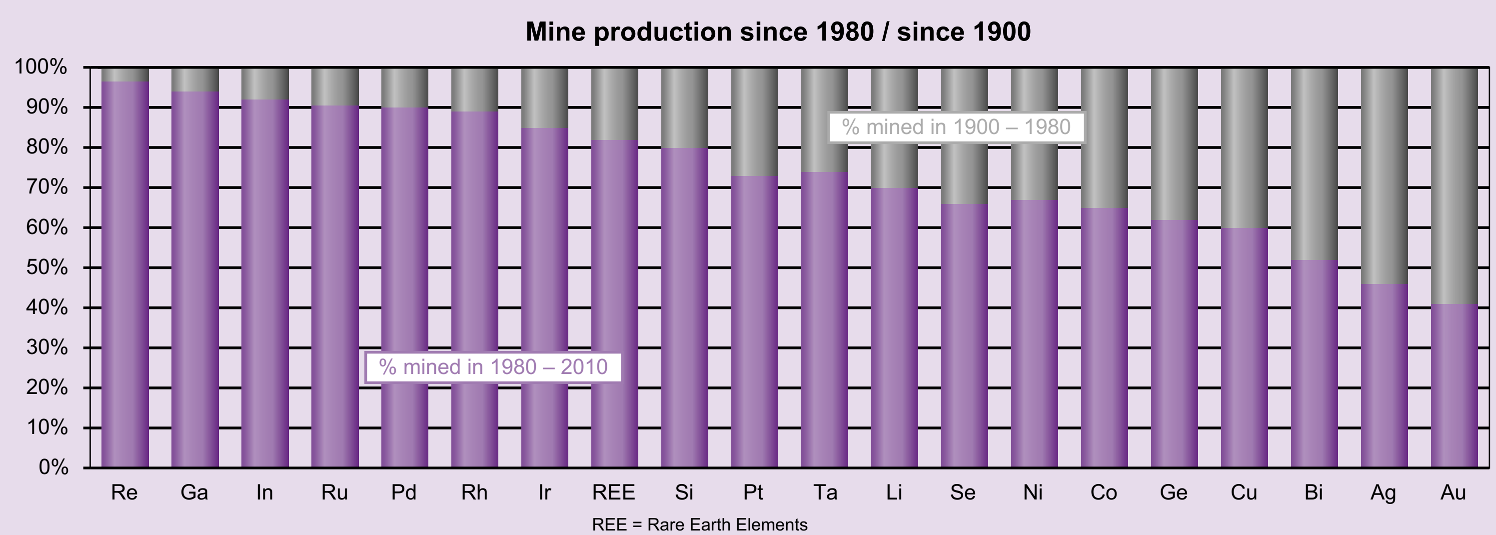
* additives in smelting, …, plating. ** includes Indium Tin Oxide (ITO) layers on glass — major application — minor application

2| Major applications for technology metals (Hagelüken, 2010)

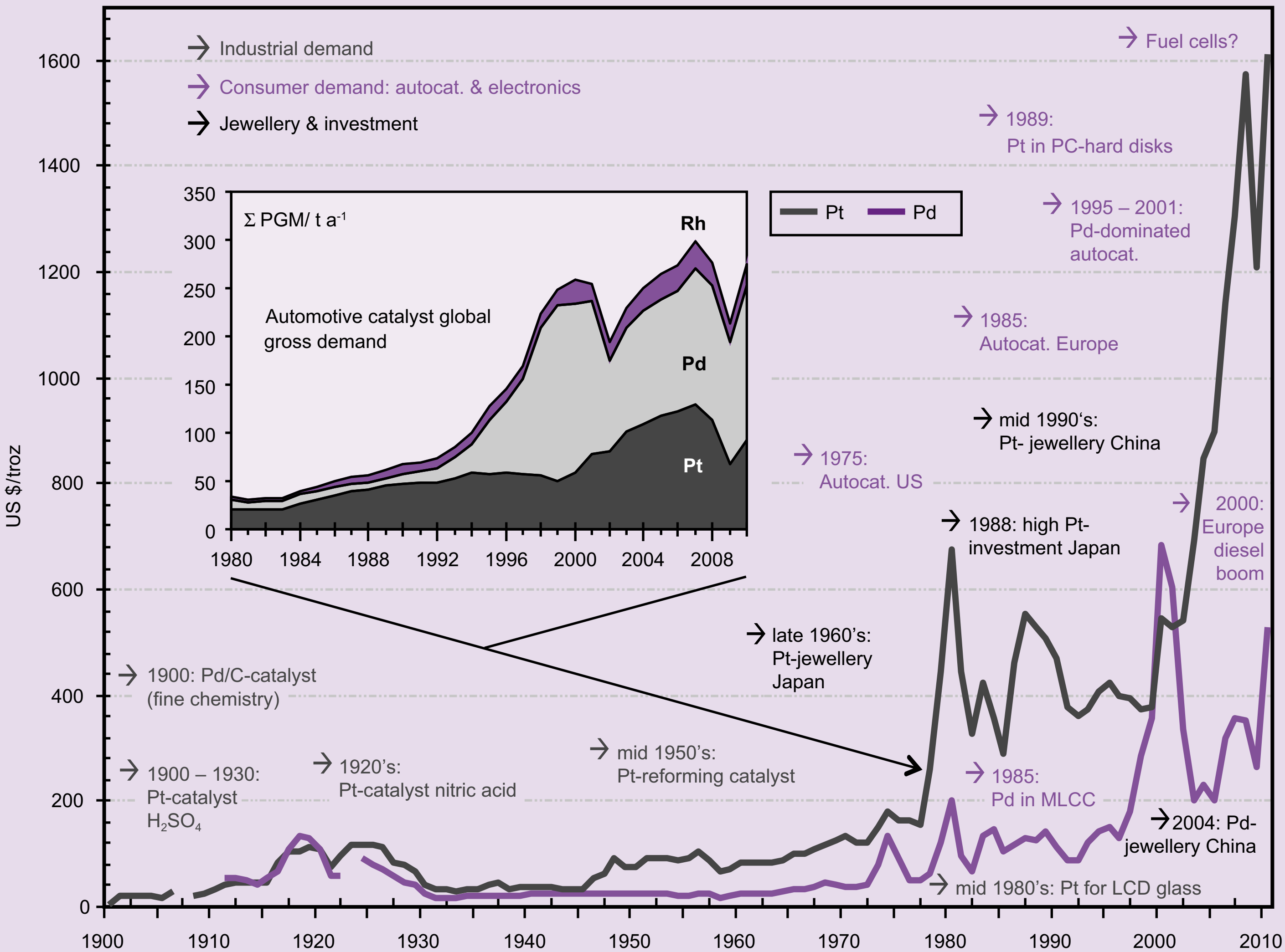
The extraordinary and sometimes unique properties of these metals are the driving forces behind their fast-growing use. These properties make many of the metals essential components in a broad range of applications. For example, the platinum group metals (PGM – Pt, Pd, Rh, Ru, and Ir) have unique catalytic properties, which are widely used in car catalysts (Pt, Pd, and Rh) as well as in process catalysts (PGM in various combinations, also with special metals). Moreover, Pt and Ru are essential for fuel cells (PEM, DMFC, and PAFC types), in high-density data storage (hard disk drives), and in super alloys. Pt and Rh are used in sensors, thermocouples, manufacturing of LCD glass, technical glass, and glass fibres. Pd is used in dentistry and Pt is used in medical (stents, pacemakers) and pharmaceutical applications. A further use of Pd is in electronics (multi-layer ceramic capacitors/MLCC), whereas Ru is also used for resistors or plasma displays and may become important for new technologies (e. g., super capacitors, super conductors, dye-sensitized solar cells and OLEDs).

The same applies for special metals (figure 2). Indium tin oxide (ITO) forms a conductive transparent layer, which is needed for LCDs as well as for thin film photovoltaics (PV), causing a soaring demand for indium. Its other applications include lead-free solders and low melting point alloys. Tellurium is used for permanent magnets, as an alloying element, in opto-electronics (photoreceptors, laser diodes, infra-red detectors, flash memory), for catalysts (synthetic fibres), and in PV, among other things. Cobalt's use is continuously growing, particularly for rechargeable batteries (NiMH, Li-ion, or Li-polymer types), which form a key component for next generation hybrid and electric vehicles, as well as in consumer electronics. Moreover, cobalt is used in combination with Re or PGM in gas-to-liquid (GTL) catalysis, for magnetic data storage, in hard metal alloys, and in super alloys.

These few examples illustrate that the use of technological solutions to build a more sustainable society depends to a large extent on sufficient supplies of technology metals, a trend that will further accelerate their demand growth (Halada, 2008). This is a fairly recent development: 80% or more of the cumulative mining of PGMs, Ga, In, REEs, and Re has been carried out over the last 30 years. For most other special metals, more than 50% of their consumption took place in this period, and even for the 'ancient metals' (Au, Ag), use from 1978 onward accounts for over 30% (figure 3).



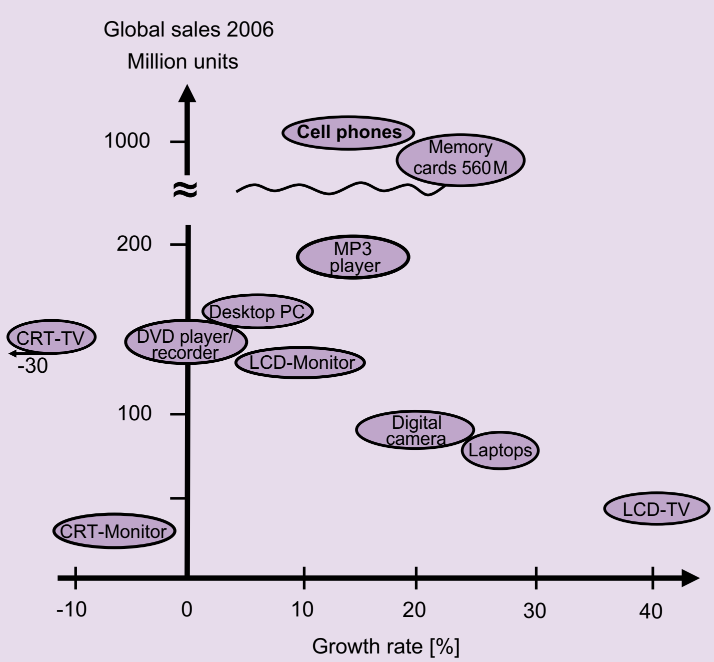
3| Global cumulative mine production 1980-2010 in relation to production since 1900



4| Long-term development of prices for platinum (Pt) and palladium (Pd) and application milestones, annual averages. Inset: global net demand for Pt and Pd since 1980

In many cases, booming demand, especially for use in mass consumer products, has driven metal prices up significantly. For example, the significant rise in platinum (Pt) and palladium (Pd) prices was mainly caused by the newly emerging demand for use in automotive catalysts (about 50% of current Pt/Pd demand) and electronics (figure 4). The PGM demand for autocatalysts increased tenfold, from 30 t in 1980 to almost 300 t in 2007.

Similar to automotive catalysts, the introduction of other new (mass) products such as LCD, PCs, and mobile phones has triggered an exponential increase in demand for the technology metals (figure 5). Furthermore, technologies such as thin film PV depend on the availability of In, Se, Te; fuel cells need Pt, and so forth. It does not seem likely that the demand for of these technology metals will be decoupled from economic growth, as opposed to ferrous and base metals which are widely used for infrastructure purposes. We can expect that apart from the industrialized countries, developing economies will also have an over-proportional need for these metals in the near future. A study predicting future metals needs for 32 selected emerging technologies (Angerer, 2009) shows that in the year 2030, the amounts of Ga, Ge, In, Nd, Sc, and Ta needed to cover the demand may exceed the total current annual worldwide production of the respective elements by a factor of up to six.



5| Unit sales and annual growth rates of selected electrical and electronic equipment (EEE) in 2006 (Hagelüken, 2010)

Developments of this kind impact prices as well. Figure 6 compiles recent mine production volumes and metal prices with average growth rates in production and prices (1978 – 2008). In the appendix of this book the price development of selected metals are shown. Apart from the general upward trend, many metals prices were highly volatile with sudden (temporary) increases, reflecting soaring demands caused by new applications and/or technologies (e. g., for Ru and In). Although partly influenced by speculation (reflecting expected future developments), a substantial contribution to rising prices comes from fundamental supply-demand developments.

	Mine production 2007 [t/yr]	Mined since 1988 [a]	Mined since 1978 [a]	Annual growth rate 1988 – 2007 [b]	Average price [USD/kg] June, 2008 [c]	1988	Annual price increase 1988 – 2007 [b]	Total price increase 1988 – 2008 [d]
Bi	5,700	35%	51%	3%	28.7	12.3	5%	132%
Co	62,300	44%	65%	2%	99.8	15.6	8%	541%
Ga	73	78%	95%	4%	525	475 [e]	1%	11%
Ge	100	36%	62%	1%	1,500	369 (in 1990)	7% (1990 – 2007)	306% (1990 – 2007)
In	510	85%	94%	9%	677	306	4%	123%
Li	333,000	54%	70%	4%	~ 2.3	58.9 [e]	–	–
REE	124,000	66%	82%	4%	–	–	–	–
Re	50	78%	96%	3%	10,000	1,470 [e]	10%	580%
Se	1,540	50%	66%	3%	72.8	21.5	7%	238%
Si	5,100,000	58%	80%	3%	2.5	1.5 [e]	0%	67%
Ta	1,400	68%	74%	9%	390	135 [e]	5%	190%
Te [f]	450	–	–	–	241	77.6 [e]	6%	210%
Ag	20,200	33%	46%	2%	546	210	3%	160%
Au	2,460	33%	40%	1%	28,622	14,043	2%	104%
Ir	4	71%	85%	5%	13,987	10,212	2%	39%
Pd	267	74%	90%	5%	14,440	4,006	6%	260%
Pt	204	58%	74%	4%	65,607	17,069	5%	284%
Rh	26	76%	90%	5%	314,424	39,633	9%	693%
Ru	36	81%	91%	9%	9	2,277	11%	316%
Cu	15,600,000	45%	60%	3%	8.4	2.6	9%	224%
Ni	1,660,000	49%	66%	3%	22.5	13.8	5%	64%

[a] Cumulated production of the last 20–30 years compared to cumulative production since 1900
[b] Based on yearly averages
[c] Monthly average price of June 2008
[d] Average price June 2008 compared to yearly average 1988
[e] U.S. metal prices until 1998
[f] USGS data are unreliable for Te since many producers were not taken into account thus, numbers given are based on unpublished documents and own estimates.

6| Current mine production, cumulated production shares and price development for selected precious and special metals. Data from USGS, GFMS Gold & Silver Survey, Johnson Matthey Platinum, unpublished, and authors' estimates

The Scarcity Debate

Under these circumstances, a discussion on potential metal scarcities has restarted that was originally triggered in 1972 by the Club of Rome's publication, 'The Limits to Growth', but then calmed down for almost two decades. As mentioned above, the use of the 'technology metals' in particular has been growing at high rates since the 1970s and correspondingly, their prices have often increased significantly. So increasingly, questions such as 'How soon will our precious element resources run out?' or 'Will there be enough affordable supply?' are raised, and occasionally, 'Are there impending severe shortages of certain metals within the next decade?'

The current debate is between two extreme positions—resource optimists versus resource pessimists. Optimists argue that essentially, market mechanisms will help overcome supply shortages. Rising metal prices will lead to new exploration and mining (of as yet uneconomic deposits) and technological advances will enable to substitute scarce metals by others with similar properties, or by economising and innovative technologies. Pessimists start with information about ore resources, compiled by the US Geological Services (USGS 2009) among others, and then divide these numbers by the current and projected annual demand. For some metals such as indium this indeed leads to rather short 'static lifetimes'. While the scientific debate is open given the many facets of the matter, media sometimes tend to bring this to rather black and white conclusions. This contribution follows a more pragmatic 'resource realist' approach, without delving into detailed discussions of statistics and single metals. The aim is to discuss the main parameters and mechanisms that govern metal scarcities and what can be done to prevent them.

Dimensions of Resource Scarcity

Three types need to be distinguished, namely, absolute, temporary, and structural resource scarcity. In this context, understanding the primary supply chain is crucial.

Absolute scarcity. Absolute scarcity is equivalent to depletion of economically mineable ore resources. In this case, all ore deposits of a certain metal—including those that have not yet been discovered by exploration—have been largely mined out and the total market demand for this metal exceeds the remaining mine output. This situation would first lead to extreme price increases and finally force substitution of that metal (or technology) in certain applications, or would severely impede further spreading of a technology (a worst case would be that a desirable technology, e. g., for energy generation, was endangered because a key metal was not available). However, within the foreseeable future such an absolute scarcity is rather unlikely, and the resource optimists' arguments count here.

Extremely high prices would make deep level mining and mining of low grade deposits economically feasible that are currently left aside. They would also trigger more exploration, leading to the discovery of new ore bodies. Exploration is very costly and time consuming so as long as mining companies have enough accessible deposits for the next two decades there is not much incentive for them to conduct additional exploration. Accordingly, data provided by USGS and other geological services do not give an account of the absolute availability of metals on the planet but rather sum up the known deposits that can be extracted economically today (reserves), or that are expected to be mineable under such conditions (resources). If exploration and mining efforts extend deeper into the earth's crust or oceans and cover a wider geographical area, possibly even into Arctic regions, substantial new metal resources are very likely to be discovered. This, however, will not come without trade-offs as in the following text.

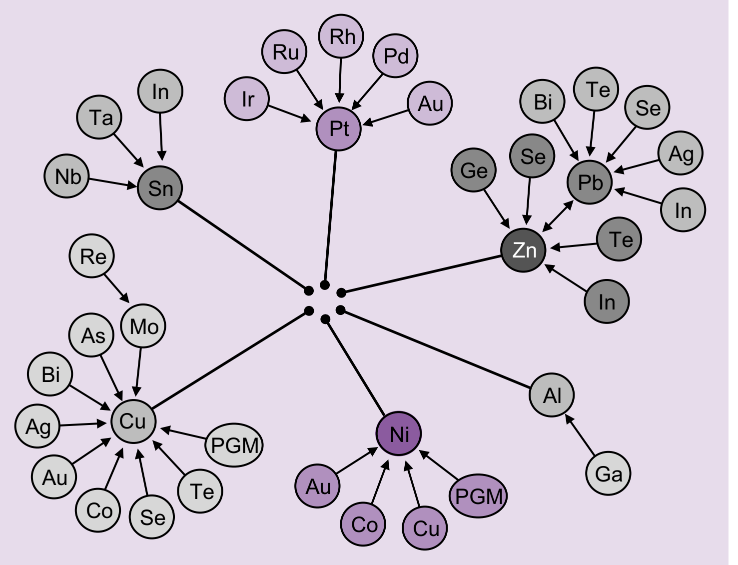
Temporary or relative scarcity. Temporary or relative scarcity, in contrast, is a phenomenon which has already been experienced. In this case, a metal supply is not able to meet the demand for a certain period of time. Reasons can be manifold. New technological developments, strong market growth for existing applications, or speculative buying by investors can drive up the demand significantly within a short time so that the mine output lags behind. Furthermore, the supply can be disrupted by political developments, armed conflicts, natural disasters, or other constraints in the mining countries themselves, within the transport of ore concentrates, or at major smelters/refineries. Temporary scarcities are a main reason for the sometimes extreme price volatility in metal markets. The risk of temporary scarcities grows with increasing concentration of the major mines or smelters in few and/or unstable regions, or in a small number of companies.

A limited number of applications making use of a particular metal leads to increased risk of scarcity as well. Often, different factors combine to accelerate such a development. For instance, in the first quarter of 2008 a soaring demand for PGMs for automotive catalysts and (speculative) investment coincided with a reduced supply from South African mines due to electric power shortages. As South Africa produces over 75% of the world's platinum and rhodium supply, prices of these metals climbed to record heights within a short time. Speculation about potential depletion of indium resources started when rocketing sales of LCD devices (monitors, TVs, mobile phones, etc), which use indium-tin oxide as a transparent conductive layer, drove up indium prices significantly.

In 2010, the tight supply situation of Rare Earth Elements (REEs) became an issue. Although sufficient reserves exist in ore deposits worldwide, more than 95% of the world's supply is currently mined in China. With an already large and growing internal demand for REEs, China restricted their exports in 2010 with a set of trade-distorting measures. This resulted in price jumps for some REEs and intensive coverage of these commonly little know elements in the public media. High technology companies outside China were suddenly faced with severe difficulties to secure REEs as raw materials for their magnet, battery, catalyst, or LED production and/or had to pay significantly higher bills. In many cases the term, rare earths, was even misinterpreted in public as a synonym for rare metals.

For the future, a production take off of thin film photovoltaics would drive up the demand for tellurium, indium, selenium, and gallium. A proliferation of electric vehicles would require large amounts of lithium, cobalt, and some REEs and fuel cell cars would need significantly more platinum than is used today in catalytic converters. Developing and expanding mining and smelting capacities is highly capital intensive, risky, and it takes many years to materialise. Hence, temporary scarcities are likely to occur more often in future.

Structural scarcity. Structural scarcity is most severe type of shortage for many technology metals, which are often not mined on their own but are found only as by-products of so-called major or carrier metals. Indium and germanium, for example, are mainly by-products from zinc mining, gallium from aluminium, and selenium, tellurium from copper (and lead). PGMs are by-products from nickel and copper mining, and combined products in their own mines. Within the PGM group, ruthenium and iridium are by-products of platinum and palladium (figure 7). Since the by-product ('minor metal') is only a very small fraction of the carrier metal, here the usual market mechanisms do not work. An increasing demand will certainly lead to an increasing price of the by-product metal, but as long as the demand of the major metal does not rise correspondingly, mining companies will not produce more, because this would erode the major metal's price. In this respect, the supply of by-product metals is price-inelastic, even a 'ten-fold increase' in its price could usually not compensate the negative impact on total revenues when there is oversupply of the major metal.



7| Combined major and minor metals production. The diagram shows which minor metals are produced as by-products of major metals.

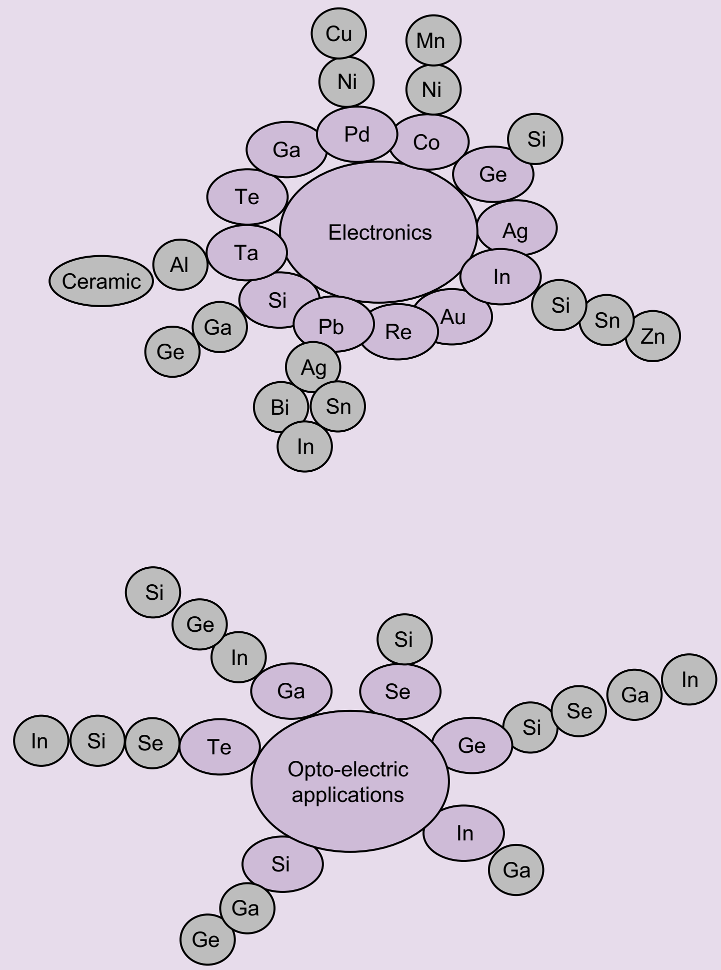
Moreover, many technology metals are important ingredients for several emerging technologies simultaneously (figure 2) so competition between applications is likely to develop and increasing demand from multiple segments is set to intensify the pressure on supply.

In the context of supply shortages and price peaks, substitution is often mentioned as a possible solution. Cases of successful replacement have already been seen in the past (e. g., Pd by Ni in certain multi-layer capacitors). Nevertheless, for technology metals, it is important to keep in mind that the replacement metal is often from the same element group. Thus, a relief in demand on one side may well lead to a new (supply) bottleneck on the other. The substitution of Pt by Pd in autocatalysts is a good example. Starting in the mid-1990s, Pt was partly substituted by the then less expensive Pd, which led to a large increase in Pd demand (figure 4). This, in turn, caused a reversal of the Pt-to-Pd price ratio and, in combination with restrictions on Pd exports from Russia, led to an all time high of the Pd price in 2000.

The semiconductors Si, Te, Ga, Se, Ge are crucial materials for emerging opto-electronics. They can substitute each other up to a point, though this will not really mitigate the problem (figure 8). It can only be overcome by increasing efficiencies in the primary supply chain (possibly leading to considerable gains) and, above all, by comprehensive recycling efforts, as will be pointed out hereafter.

In addition to pricing, legislation can also be a driver for substitution. The ban of lead (Pb) in solders (after 2000) caused an increase in the demand for tin (Sn), silver (Ag), and bismuth (Bi). The latter two metals are partially produced as by-products of lead mining; thus, reducing the demand for Pb led to extra pressure on the supply of Ag and Bi. Indium (In) could also be used in lead-free solders, but this would exert increased pressure on the indium price (Appendix figure A85), which already increased temporarily by a factor of 10 after 2003 due to high demand for LCD screens and, later on, photovoltaic applications. Generally speaking, ignoring the fact that many technology metals are by-products and that structural scarcity is possible while substitution opportunities are limited is a weak point in the resource optimists' argumentation.

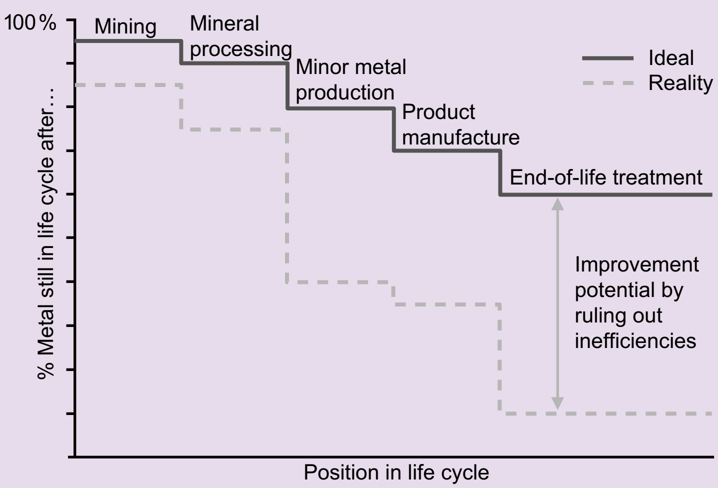
Independent of whether or not supply constraints are likely, the impact of mining lower grade ores and extracting ores from more challenging deposits should not be overlooked. It will inevitably lead to increasing costs, energy consumption, and emissions, it will impact the biosphere (rain forest, arctic regions, oceans), and it can increase the dependence on certain world regions ('battle for resources'). This can impose significant constraints on emerging technologies, unless effective life cycle management can boost the overall resource efficiency and promote the use of recycled or secondary metals in the years to come.



8| Substitution of metals in electronics and in opto-electric applications. The inner spheres show the elements used in the applications; the outer spheres indicate possible replacement elements (Hagelüken, 2010).

Improving Metal Resource Efficiency

Inefficiencies in primary production, manufacturing, product use, and recycling due to missing or inadequate technologies add up to high losses (figure 9) and reduce both the availability and resource efficiency of technology metals.



9| Graph showing (minor) metal losses during the life cycle indicating the ideal situation and the current state. Although certain losses are inevitable, process and system improvements can significantly increase minor metal availability (Hagelüken, 2010).

Overcoming such inefficiencies could enable a 'quick win' and result in a gain in supply security. Improvement options can be found on all levels.

In primary production by maximising overall extraction yields:

- Invest to enable recovery of coupled minor metals by installing available technology or conduct research to develop new technologies.
- Optimise process yields by adjusting existing processes and operating conditions.
- Adjust input quality/composition.
- Recover minor metals from historic primary stocks[1] such as stockpiled tailings and slag as well as unmined parts of ore bodies.
- Conduct exploration focusing on minor metals to increase their reserve base.

In manufacturing by minimising production losses:

- Improve the efficiency (yield) of manufacturing and recycling processes.
- Develop recycling technology and set up capacities to reclaim currently not-recycled manufacturing scrap.
- Optimise product design (select appropriate material combinations for use and recycling).
- Recycle historic stocks (accumulated from production in the past) and newly accumulated stocks of production scrap.

During the use phase of products, dispersion of critical metals needs to be avoided. However, as figure 9 indicates, the largest optimisation gain can be achieved by better product management in the end-of-life phase, as will be elaborated in the main chapter 'Recycling and Loop Concept for a Sustainable Usage'. More in-depth research is needed to quantify the improvement potentials. How much additional supply of technology metals could be obtained by removing the inefficiencies along product lifecycles? To answer this, the following issues need to be addressed.

For primary production:

(a) Ore ratios of by-product metals in main deposits
(b) Technical efficiency of primary by-product recovery: What percentage will still be lost in side streams in an optimal case if the smelter is equipped with separation technology?
(c) What would be the resulting optimal supply ratio of minor to major metal (e. g., In:Zn)? What does this mean for quantifying the accessible reserves and future production volumes of minor metals (from the moment where 'all' inefficiencies in the primary production chain have been solved, the primary minor metal's production being directly (and price inelastically) coupled to the production of the major metal?
(d) What technologies and investments are required to deploy new equipment for by-product recovery and to improve the efficiency of existing processes?

[1] Old tailings, slag deposits, or other mining and smelting residues from past activities can contain significant (minor) metal resources. With today's mineral processing technologies, e. g., fine-grained minerals could be extracted from tailings that have slipped through in the past. Improved (metallurgical) processes could recover elements thought of as unrecoverable so far; and increased metal prices can turn the focus onto certain metals which were not targeted for recovery in the past and therefore discarded completely.

For product manufacturing:
(a) At what stage do losses of minor metals occur?
(b) What are the properties (composition) of such residues and which technologies are available for metals recovery?
(c) How could manufacturing processes and recycling technologies be improved and what additional minor metal yields would that generate?

For recycling of end-of-life (EoL) devices:
(a) What (minor) metal recovery results could be achieved for defined (consumer) products if these would enter into an ideal industrial recycling chain with optimized internal interfaces and state-of-the-art individual processes?
(b) Which products cannot be recovered satisfactorily even in an optimal recycling chain (e. g., car electronics) and what does this mean for product design and (recycling) technology innovation.
(c) How does this technical improvement potential compare quantitatively to the structural inefficiencies in (consumer) product life cycles?

In summary, to secure a sustainable metal supply for future generations, mining and recycling need to evolve as a complementary system where the primary mining output is essentially used to cover inevitable life cycle losses and market growth and recycling of EoL products contributes increasingly to the overall metal supply. Moreover, effective recycling systems would mitigate the climatic impact of metal production, which is energy intensive, especially in the case of precious metals mined from low concentrated ores (e. g., Au mined at 5 g/t from 3000 m underground). The mining of annually 2500 tonnes of gold worldwide generates some 17,000 tonnes of CO_2 per tonne of gold produced (based on ecoinvent 2.0 database of EMPA/ETH Zürich), or 42 million tonnes CO_2 in total (see also figure 1).

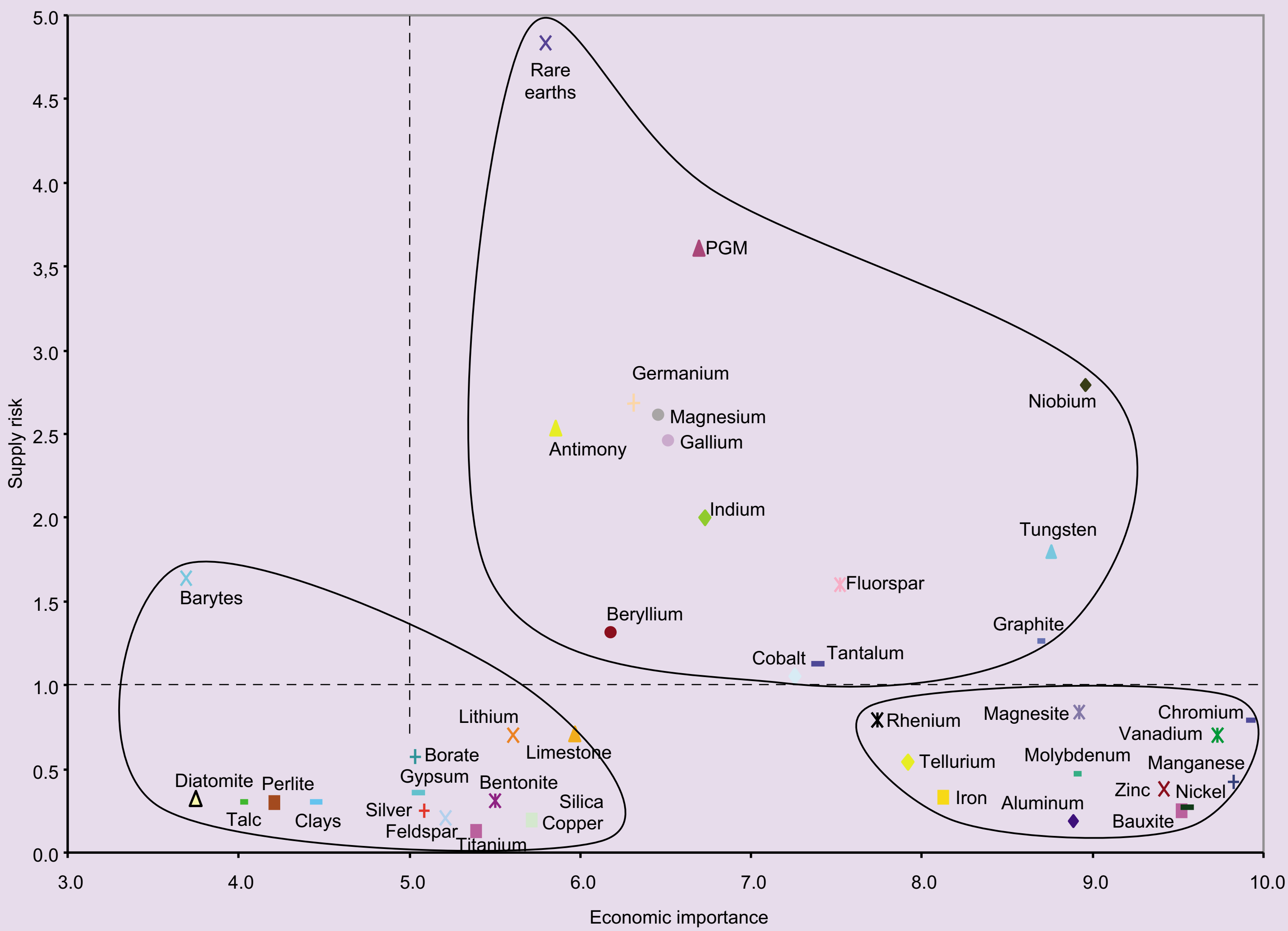
For PGMs, the ore grade and specific CO_2 impact are of the same magnitude while copper mining 'only' causes 3.5 tonnes CO_2/tonne Cu but nevertheless adding up to 56 million tonnes at a production volume of 16 million tonnes per annum. Some mass products are relatively rich 'bonanzas' in comparison, e. g., computer motherboards yielding around 250 g gold per tonne, mobile phones handset with 350 g Au/tonne, or automotive catalytic converters with some 700 g per tonne of PGM. If effective collection systems and state-of-the-art recovery processes are employed, metal retrieval from such sources entails only a small fraction of energy consumption and CO_2 emissions compared to mining.

Critical Metals

In recent years, a number of studies (e. g., National Research Council, 2008; Buchert, 2009 and EU Commission, 2010) systematically looked into which metals need to be regarded as critical from a certain country's or region's perspective. Although the studies' scopes and methodologies were not identical, they used common criteria to assess criticality by considering the economic/strategic significance on one side and the degree of supply security on the other. A number of metals were identified as critical in most of the studies, including the rare earths elements, the platinum group metals, indium, and germanium.

During 2009 and 2010, the European Commission's ad hoc working group on defining critical raw materials evaluated 41 non-energy raw materials, 14 of which were identified as critical for the EU economy. The report follows a concept of relative criticality, which means that a particular raw material is labelled as critical if the risk of supply shortage and its impact on the economy is higher than for most other raw materials. Two risk types were considered. The 'supply risk' took into account the political-economic stability of the producing countries, the level of concentration of production, the potential for substitution, and the recycling rate. The assessment was based on a quantitative aggregation of indicators. In addition, an 'environmental country risk' was evaluated qualitatively to assess the probability of countries with weak environmental performance taking measures to protect their environment and, in doing so, endanger the raw material supply to the EU.

Figure 10 shows the results. The identified 14 critical raw materials fall in the top right cluster with relative economic importance and relative supply risk both high. The environmental country risk metric did not change the list of critical raw materials. These are (in alphabetic order): antimony, beryllium, cobalt, fluorspar, gallium, germanium, graphite, indium, magnesium, niobium, PGMs, REE, tantalum, and tungsten. The report includes a number of recommendations for follow-ups and further support as well as for political provision in the fields of mining/exploration, trade, recycling, substitution, and material efficiency (EU Commission, 2010).



10| Raw materials investigated by the EU critical raw materials working group. The top right cluster comprises the 14 raw materials identified as critical (EU Commission, 2010).

Trading Markets, Pricing and Metals Management

Historically, several important trading centres for precious metals have developed in Europe, the U.S.A., and Asia. Participants in precious metals markets have formed internationally reputed trade organisations and their members trade among each other as well as with non-members. Exchanges have been established where precious metals can be traded spot and for future delivery, eliminating counterparty risk. Trade organisations and exchanges have agreed on internationally respected standards for precious metals in terms of metal fineness, physical weight denominations and acceptable refiners.

Today, many precious metal market participants use electronic trading platforms, facilitating a virtually uninterrupted 24-hour trading day for many precious metals around the world. Working with precious metals should include addressing associated risks adequately, the most prominent of which (apart from many others) is the risk of loss due to unfavourable metal price changes. This implies the need for comprehensive metals management as indispensable for any organisation working with precious metals.

Precious Metals: Trading Markets and Pricing

London is the world's most important physical gold and silver trading place today. Its roots go back to the necessity to trade primary gold and silver from the former British colonies. Bullion transactions in London can be traced back to the 17th century.

The beginnings of the London market's structure and many features of the marketplace as it is today can be ascribed to the introduction of the London Silver Fixing in 1897 and the London Gold Fixing in 1919. The numbers and types of the London market's participants grew markedly in the early 1980s. When the Financial Service Act was introduced in England in 1986, the formation of the 'London Bullion Market Association' (LBMA) was brought about and it was established in late 1987 in close co-operation with the Bank of England.

The LBMA is a trade organisation acting as a co-ordinator for activities conducted on behalf of its members and other participants in the London gold and silver market. LBMA members include banks, fabricators, refiners, transport companies, and brokers. One of the LBMA's primary objectives is to promote refining standards. Refiners who comply with the LBMA's standards and rules are listed in their 'Good Delivery List of Acceptable Refiners' (gold and/or silver).

A standard 'London Good Delivery' gold bar must have a minimum fineness of 99.5% and the weight of such bars is generally close to 400 troy ounces (12.5 kg), although a weight range of 250 to 430 fine ounces of gold content per bar is allowed.

A standard 'London Good Delivery' silver bar must have a minimum fineness of 99.9% and bars generally weigh 1,000 troy ounces (31.1 kg), although a weight deviation of some 10% is permissible.

LBMA market members provide two-way bid and offer quotations in gold and silver for spot, forward, options and deposits or loans throughout the day. Business is generally conducted via telephone or with the help of electronic trading systems. Additionally, London offers the London Gold and Silver Fixings as unique services. These fixings provide globally accepted ratings as a pricing basis for a range of industrial contracts as well as for cash-settled swap and option transactions.

The London Gold Fixing is performed twice daily at 10.30 a.m. (London time) and 3.00 p.m. by telephone between five Market Making Members of the LBMA. Clients can place orders with the trading rooms of these Fixing members, who net all orders before communicating the net interest to their representative at the Fixing. If buy and sell interests are not balanced, the gold price is adjusted up or down and clients can adjust their orders accordingly. Finally, when all sell and buy orders are matched, the price is declared 'fixed' and orders are executed on the basis of that price.

Settlement (payment and delivery) for any spot business is within two London business days after the day of the deal. Metal is usually credited on an unallocated London weight account ('loco London') in form of standard Good Delivery gold bars, unless negotiated otherwise against a premium for a different location or form.

The London Silver Fixing provides the very same features as the Gold Fixing, except that the Fixing is only performed once daily at 12.00 noon in London. Metal purchases are credited on an unallocated weight account in form of Good Delivery silver bars.

It is worth noting that the bulk of Good Delivery gold and silver bars serve for investment purposes only. Many industrial applications using gold or silver do not require the metal in its standard Good Delivery bar form but rather in form of grains. Such grains are produced by pouring hot molten metal through a special sieve into water, resulting in small, drop-shaped pieces of metal. Obviously, the surface of 400 oz. tr. of such grains is a multiple of that of a 400 oz. tr. gold bar and it is much easier to apportion, remelt or chemically dissolve such grains for industrial application purposes.

Next to gold and silver, London has also developed alongside Zürich into a major trading centre for platinum and palladium. In 1973 the London Platinum Quotation was introduced as a forerunner of today's Platinum and Palladium Fixings. In 1979, the leading London and Zürich traders reached an agreement to standardise the specifications and provenance which they would accept as 'Good Delivery'. The London Fixings for Platinum and Palladium were established in 1989.

In the same way as LBMA was established as a trade organization of participants in the gold and silver markets, a trade organisation for platinum and palladium was formed, the 'London Platinum and Palladium Market' (LPPM). As many market players trade in more than two precious metals, there is a great deal of membership overlap between the LBMA and the LPPM and both organisations co-operate closely.

The LPPM promotes refining standards for Good Delivery platinum and palladium. Refiners who comply with the LPPM's standards and rules are listed in the LPPM's London/Zürich 'Good Delivery List of Acceptable Refiners'. A London/Zürich Good Delivery platinum or palladium plate or ingot/bar must have a minimum fineness of 99.95% and a weight of between 1 kilogram (32.151 troy ounces) and 6 kilogram (192.904 troy ounces).

The London Platinum and Palladium Fixings are conducted twice daily at 9.45 a.m. and 2.00 p.m. (London time) by four Full Members of the LPPM by telephone. The process follows a pattern similar to the gold and silver Fixings, arriving at a 'Fixing Price' when buying and selling orders are matched.

In general, market practices and instruments for platinum and palladium operate very similar to gold and silver, although market liquidity and market breadth are both smaller and thus bid/ask spreads are usually much wider. Consequently, a greater share of spot business is conducted via the Platinum and Palladium Fixings. Settlement for transactions conducted through the Fixings is within two London business days and metal usually is credited on an unallocated Zürich or London weight account in form of standard Good Delivery ingots.

A good part of industrial applications require metals in form of sponge or powder and not in form of ingots (e. g., for producing compounds). Thus, metal sponge usually carries a premium over the ingot form, and fabricators take the form and quality of metals into account when quoting prices to industrial clients.

Some members of the LPPM as well as other market participants also trade other platinum group metals apart from platinum and palladium. These metals—rhodium, ruthenium and iridium—are used for specific industrial applications and physically available in sponge or powder form only. However, as the annual mine supply of these metals is much smaller than any other precious metal, markets for these metals are much less liquid and there are much less market participants.

Zürich is the second most important trading centre for physical precious metals, with roots in refining and selling South African gold mining output. It has developed into the major trading hub for physical platinum and palladium ingots from South African mines as well as for precious metals from Russia. Market practices equal those of London.

New York has established itself as the major exchange centre for traded futures, that is, standardised contracts stipulating a binding price for settlement at a future date. Such contracts play an important role for hedging price exposure as well as speculation and investment.

The major exchange for precious metals in the U.S. is the New York Mercantile Exchange (Nymex). Next to many other commodities, gold and silver futures are traded in its Comex Division while platinum and palladium futures are traded in its Nymex Division. Nymex Contracts are standardised in terms of weight per contract: 100 troy ounces (~ 3.11 kg) for gold, 5,000 troy ounces (~ 155,52 kg) for silver, 50 troy ounces (~ 1.56 kg) for platinum, and 100 troy ounces (~ 3.11 kg) for palladium, and in terms of future due dates.

Obviously, a metal transaction to be settled at a future date can be negotiated between two trading partners directly as well (e. g., between a bank and a refiner), and such transactions are called over-the-counter (OTC) 'forwards' rather than 'futures' traded on an exchange. However, exchange traded contracts avoid the risk of counterparty default, as the Nymex clearinghouse acts as counterparty to every trade. To safeguard Nymex, all such contracts require payment of an initial margin and, as prices change, a variation margin.

The advantage of OTC contracts is their flexibility, as these can be adjusted to the specific needs of the two parties (from a weight and a forward date perspective). Counterparty risk and higher spreads are disadvantages of OTC contracts compared with exchange traded contracts.

Any futures contract can be exchanged for a physical position of equal quantity for a fee relative to the metal price, known as EFP (exchange for physical). The size of the EFP depends on the spread between spot price and future price. Usually the future price of a metal is higher than the spot price (the difference is then called contango), as carrying cost of the metal (interest, insurance, storage) are added to determine a future price. However, spot metal may be in short supply or extremely high demand at times and market participants expect future prices to be lower. In this case, the spot price will be higher than the future price (this difference is called backwardation).

It is worth noting that only a small fraction of all futures traded at Nymex ultimately lead to a physical delivery. As the bulk of these contracts is initiated for hedging price exposure or speculation/investment, such contracts usually are closed by entering an opposite trade of the same quantity and due date. This also explains why trading volumes in a metal at Nymex exceed the annual mine production of that metal many times.

Apart from future contracts, standardized option contracts can also be traded at Nymex. Two basic option types exist. The first type involves a buyer of an option receiving the right to purchase (= call option) a metal at a future date at an agreed price (= strike price) from his counterparty. The second type allows a buyer of an option to sell (= put option) metal to his counterparty at a future date at an agreed price. In both cases, the option buyer pays the seller a premium depending on price and forward due date (= expiration date). Option trading units at Nymex usually are the same quantities as stipulated for the respective future contracts.

Options can also be agreed upon between two counterparties in the OTC market—and as such tailored to the specific needs of the parties. Advantages and disadvantages compared to exchange traded options are the same as mentioned above for futures and forwards.

A real-life example for a company utilizing futures/forwards or a put option could be the owner of scrap metal (containing some gold) delivered to a refiner for extracting. At the time of delivery, the owner could choose to sell forward the scrap's gold content to a date after the gold had been recovered, say, at 905 $ per troy ounce (oz. tr.). However, if he assumed that the gold price would rise until then, he might purchase a call option to lock in a certain price in advance, say, 905 $ per oz. tr. (strike price). This would leave him all of any upside potential if the gold market did rise. If the gold price was above his strike price at the call option expiration date, say 920 $ per oz. tr., he would let his put option right expire and sell his gold to the spot market at 920 $. However, if the gold price was below his option strike price of 905 $ per oz. tr., say 890 $, at the expiration date he would exercise his option and receive 905 $ per oz. tr. from the option seller.

The above example illustrates that risk of options is asymmetrical for their buyers and sellers. Whereas the maximum risk for the buyer is the option premium paid to the seller, the option seller could face a large risk unless he is hedged otherwise. Thus, option premiums can be very high in times of hefty single-directional metal price movements.

Tokyo has been the major trading centre for precious metals in Asia for many years. From the Tokyo Gold Exchange (TGE), founded in 1982, the Tokyo Commodity Exchange (TOCOM) developed in 1984 when TGE merged with two older Tokyo exchanges (trading in textiles and rubber). Today, TOCOM offers forward contracts for silver, platinum, palladium and many other commodities apart from gold. Gold options are available as well.

Contracts at TOCOM are standardised in terms of weight per contract (gold 1 kg, silver 30 kg, platinum and palladium 0.5 kg each) and in terms of the future due date. If physical delivery is required, delivery weight is the same as weight of one contract except for palladium, which requires 6 contracts (3 kg) as minimum delivery weight. However, most TOCOM contracts are closed out before their due date by an offsetting contract and no delivery takes place. All TOCOM forward contracts require margin payments.

In 2007 and 2008, TOCOM introduced 'Mini Contracts' for gold and platinum to allow smaller investors to speculate (contract size is no more than 100 g for both metals). These mini contracts are cash-settled only, that is, the price difference between contract price and spot price is paid or received at the due date (no physical delivery is possible).

Shanghai is the youngest trading centre for precious metals in Asia. On Oct. 30th 2001 the Shanghai Gold Exchange opened after having been founded by the People's Bank of China (PBC) in order to facilitate trade in gold, silver and platinum and to curb smuggling of precious metals into China from Hong Kong and other places. Membership to this exchange is restricted to banks and corporations registered in China and approved by the PBC. Members can choose to conduct spot and futures transactions.

Other markets: Long before the Shanghai exchange, precious metals markets were operating in other parts of Asia. In Hong Kong, a 'Chinese Gold and Silver Exchange Society' was founded in 1910, and today platinum and palladium are traded by its participants as well. Singapore and Sidney should also be mentioned as local Asian precious metals trading centres. Last but not least, gold is traded locally in Dubai and Mumbai due to their significance as jewellery markets.

The many trading centres worldwide facilitate a near continuous 24-hour trading day for many precious metals around the world. Today, many market participants use Electronic Trading Platforms operated by exchanges, banks, and other providers. These platforms allow real-time price quotes and in many cases also provide for immediate transactions in the spot, forward/futures and options markets. Some platforms are web-based while others require special hard and software. The proliferation of electronic platforms and the internet have greatly enhanced price transparency for many of the instruments traded in precious metal markets.

Metals Management

Any organisation working with precious metals must make sure that risks associated with these are adequately addressed. The most prominent precious metal risk to consider is the risk of loss due to unfavourable metal price changes.

For instance, a fabricator of a product containing 500 oz. tr. of platinum must make sure that he will at least achieve the same price that he paid for the precious metal when he sells his product to his customer. There are two principal ways to eliminate price risk for a fabricator:

- The metal for the product is purchased at a price agreed upon with the customer at the time of purchase.
- The customer purchases the metal himself elsewhere and delivers it physically to the fabricator (metal consignment/bailment).

A metal refiner may be in a reverse situation, often being required to purchase the metal content of scrap material from a customer (e. g., platinum bought from a scrap yard customer selling spent autocatalysts). The refiner must make sure that he can sell such platinum at a price not below the price he paid to the scrap yard customer. In order to hedge price risks, fabricators and refiners can make use of spot, forward/future and option instruments available in precious metals markets.

However, it may not always be possible or practical to purchase or sell the very amount of metal involved in a particular customer transaction (e. g., the quantity involved might be too small for a market trading transaction). In such cases the fabricator or refiner will incur a 'metal position' (metal which is priced but not bound to any immediate or future offsetting sales or purchase commitment). Open metal positions thus need to be strictly limited and controlled independently within an organisation.

Apart from the price risk—which often may include a currency risk—there are many other risk areas associated when working with precious metals. For instance physical supply risks (form, quality and liquidity of metals) need to be managed and the risk of loss or theft in process as well as any risk with regard to the legal environment of the operations (e. g., tax laws and import/export regulations). This implies the need for comprehensive metals management as indispensable for any organisation working with precious metals.

Special Metals (Indium, Selenium, Tellurium): Trading Markets, Pricing and Metals Management

Special metals (indium, selenium, tellurium) belong to the group of minor metals. For minor metals, there is no possibility to cover the risk of losses due to unfavourable metal price changes with official counterparties. The main reason is that the number of transactions is too small to justify these metals being traded at official exchanges such as the London Metal Exchange. As a consequence, minor metals, which are sometimes traded at high prices (e. g., indium was traded in April 2011 above 600 $/kg), cannot be officially hedged. As a consequence, the risk has to be covered back-to-back or with long-term supply contracts versus long-term sales contracts, or the risk is simply not covered.

Quite generally, the market price is a function of supply and demand. Metal trade publications such as Metal Bulletin, Metal Pages, Asian Metal, or MetalPrices.com publish weekly or twice weekly metal quotations. Such publications issue pricing references for specific metals and purities, delivered at specific locations. References usually include low, average, high prices. There are no standards available, which means that a publication may quote a price for a metal but for a different purity than the one another publication refers to.

Price setting is not well documented, there are no general rules available. Usually, the publication will follow some internal procedure, for example:

- To contact producers, end users, traders, and distributors to hear their opinion and ask for prices related to deals that were booked in the past week
- To evaluate current and future supply-demand balances or imbalances
- To follow market trends
- To follow current and future uses of a specific metal within its main applications
- To incorporate government interferences into the price model
- Etc.

Pricing can be in Euro (€), US-Dollar (US$) or in any other currency.

Sometimes the price difference between spot prices and long term prices can differ substantially; this is usually a direct consequence of a supply-demand imbalance.

The actors in the minor metals industry (buyers and sellers), more particularly in the special metals industry, usually refer in one way or another to one of the published prices to negotiate a spot deal or a long term contract. For long-term contracts, a seller and a buyer will often agree to a price formula that is linked to some published price.

Glossary

CRT	Cathode ray tube
DMFC	Direct methanol fuel cell
DVD	Digital video disc
EEE	Electrical and electronic equipment
EFP	Exchange for physical
EMPA	Swiss federal laboratories for materials testing and research
EoL	End-of-life
ETH	Swiss federal institute of technology (Switzerland)
GFMS	Gold fields mineral services
GTL	Gas to liquid
IT	Information technology
ITO	Indium tin oxide
LBMA	London bullion market association
LCD	Liquid crystal display (display technology)
LPPM	London platinum and palladium market
MLCC	Multilayer ceramic capacitor
NiMH	Nickel metal hydride (battery technology)
Nymex	New York mercantile exchange
OLED	Organic light-emitting diode
OTC	Over the counter
PAFC	Phosphoric acid fuel cells
PBC	People's bank of China
PEM	Polymer electrolyte membrane
PGM	Platinum group metals
PV	Photovoltaics
REE	Rare earth element(s)
TGE	Tokyo gold exchange
TOCOM	Tokyo commodity exchange
USGS	United states geological survey

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