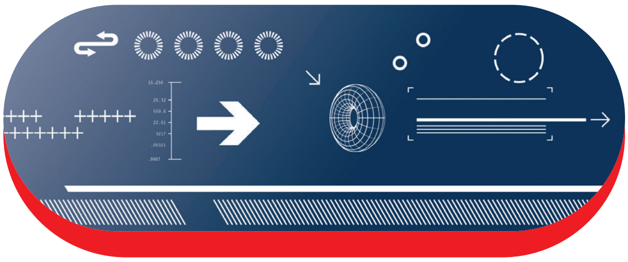
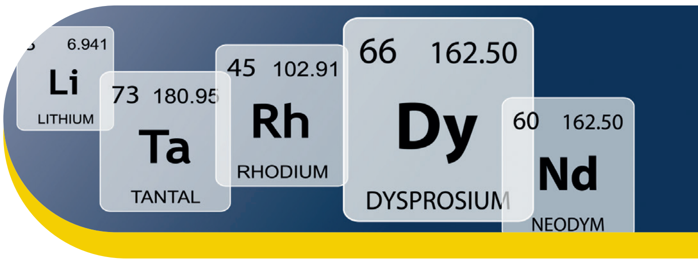
DERA German Mineral Resources Agency
Federal Institute for Geosciences and Natural Resources

28 DERA Rohstoffinformationen





Raw materials for emerging technologies 2016

»commissioned study«

Summary

Editor: German Mineral Resources Agency (DERA) at the
Federal Institute for Geosciences and Natural Resources (BGR)
Wilhelmstraße 25 – 30
13593 Berlin/Germany
Tel.: +49 30 36993 226
dera@bgr.de
www.deutsche-rohstoffagentur.de

Autors: Frank Marscheider-Weidemann, Sabine Langkau,
Torsten Hummen, Lorenz Erdmann, Luis Tercero Espinoza
Fraunhofer-Institut für System- und Innovationsforschung ISI
Breslauer Str. 48
76139 Karlsruhe/Germany

Gerhard Angerer
Karlsruhe/Germany

Max Marwede, Stephan Benecke
Fraunhofer IZM, Berlin/Germany

Contact
DERA: Ulrike Dorner | ulrike.dorner@bgr.de

Reference: Marscheider-Weidemann, F., Langkau, S., Hummen, T., Erdmann, L.,
Tercero Espinoza, L., Angerer, G., Marwede, M. & Benecke, S. (2016):
Summary | Raw materials for emerging technologies 2016. –
DERA Rohstoffinformationen 28: 13 S., Berlin.

Date: March 2016

Cover Images: ©BGR

ISSN: 2193-5319

Berlin, 2016

Federal Ministry
for Economic Affairs
and Energy

The Federal Institute for Geosciences and Natural Resources
is a technical and scientific agency of the Federal Ministry for
Economic Affairs and Energy (BMWi).

Fraunhofer
ISI

Raw materials for emerging technologies 2016

»commissioned study«

Commissioned by the German Mineral Resources Agency at the
Federal Institute for Geosciences and Natural Resources, Berlin

Summary

Abkürzungen

A	
Ag	Silver
Al	Aluminium
Au	Gold
B	
Ba	Barium
Bi	Bismut
C	
Ca	Calcium
CAGR	Compound Annual Growth Rate
Cd	Cadmium
CFRP	Carbon Fiber Reinforced Plastic
Co	Cobalt
Cr	Chromium
Cs	Caesium
Cu	Copper
D	
Dy	Dysprosium
E	
e-cars	Cars with electric motors
F	
Fe	Iron
G	
Ga	Gallium
Gd	Gadolinium
Ge	Germanium
H	
Hg	Mercury
HRE	Heavy Rare Earth Elements
I	
IC	Integrated Circuit
In	Indium
IR	Infrared
L	
La	Lanthanum
LED	Light Emitting Diode
Li	Lithium
LRE	Light Rare Earth Elements
M	
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
N	
Nb	Niobium
Nd	Neodymium
Ni	Nickel
P	
Pb	Lead
Pd	Palladium
Pr	Praseodymium
Pt	Platinum
R	
Re	Rhenium
RFID	Radio Frequency Identification
Ru	Ruthenium
S	
Sb	Antimony
Sc	Scandium
Se	Selenium
Si	Silicon
Sn	Tin
SOFC	Solid Oxid Fuel Cell
Sr	Strontium
T	
Ta	Tantalum
Tb	Terbium
Te	Tellurium
Ti	Titanium
V	
V	Vanadium
W	
W	Tungsten
WLED	White Light Emitting Diode
X	
XtL	Collective term for synthetic fuel processes (coal-to-liquids, gas-to-liquids, biomass-to-liquids)
Y	
Y	Yttrium
Z	
Zn	Zinc
Zr	Zirconium

Summary

The study “Raw materials for emerging technologies 2016” is part of the German Mineral Resources Agency’s (DERA) monitoring of raw material demand. The study’s objective is to inform industry and policy makers about current demand, supply, and price trends for primary mineral commodities and intermediate products needed for the first stages of value creation. The aim is to be able to identify critical trends on international raw material markets in plenty of time and to develop possible alternatives and adaptation strategies in companies.

The complete study (in German) can be downloaded on the DERA homepage at:

www.deutsche-rohstoffagentur.de

Background and objectives

It is necessary to have a sound and up-to-date knowledge base about possible demand developments in mineral raw materials in order to better estimate possible long-term price and supply risks. In particular, key and emerging technologies that are resource-intensive or resource-sensitive can trigger strong demand impulses and have a significant influence on commodity markets.

Key and emerging technologies comprise, on the one hand, efficiency improvements in existing systems (such as conventional power station technology or lightweight steel construction with tailored blanks), but also on the other hand completely novel technologies (such as alternative energy generation or new vehicle propulsion systems). These technologies can trigger revolutionary innovation leaps beyond the confines of individual economic sectors.

For industrial nations as high-wage countries, competitive advantages on the global market are gained mainly through technical innovations. The research and development race that was sparked as a result continuously pushes the pace of innovation. This race can be measured, for example, with the rising number of patents. At the same time, German industry is almost completely dependent

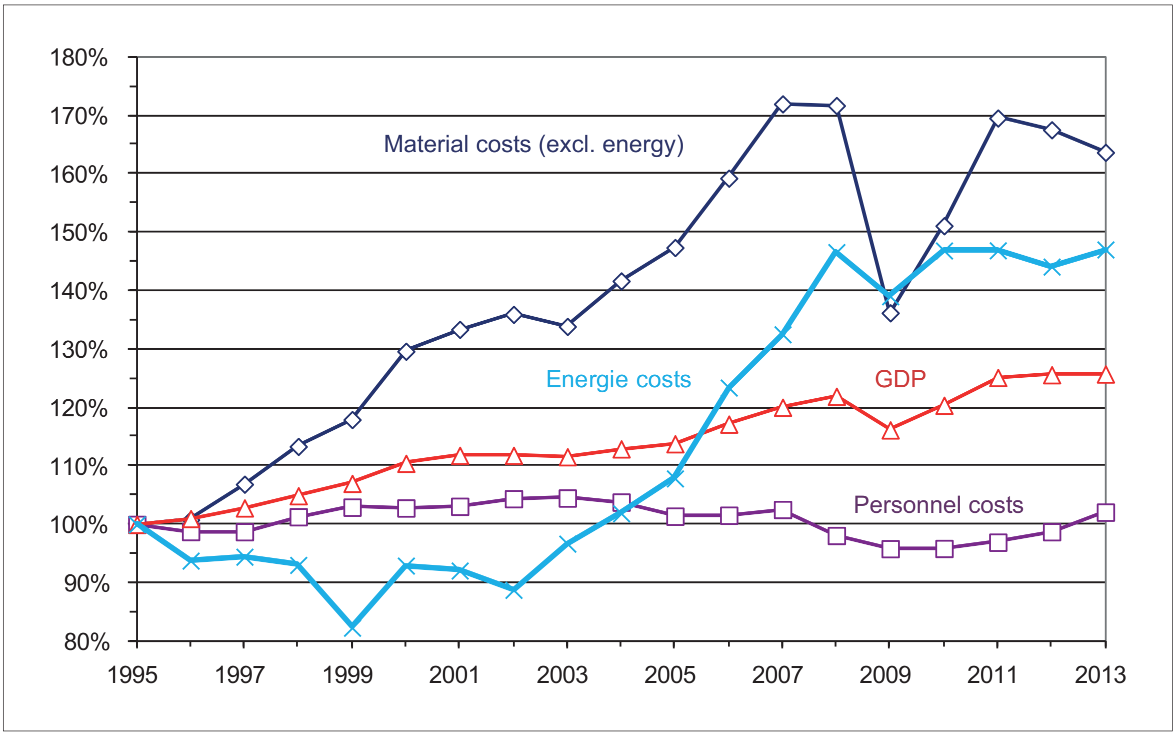


Figure 1: Cost development (adjusted for inflation) in Germany’s manufacturing industry

on imports, not only of energy resources, but also of metals. Securing an uninterrupted supply of raw materials is therefore an important task to guarantee the international competitiveness of German industry.

Material costs represent the biggest cost limit by far for the manufacturing industry. Admittedly, these costs have not increased over the last decade, but they have remained at a consistently high level compared to the previous decade as shown in Figure 1.

Table 1 shows the manufacturing sector's shares in the gross value of production for the year 2013 according to the German Federal Office of Statistics. The material costs shown here only partly comprise raw material costs. This is because they also include externally purchased primary products such as auxiliaries, operating materials and supplies including bought-in components and water. In addition to overall global economic growth, unusually strong worldwide growth in emerging technologies can have a significant impact on the global demand for specific commodities. The impacts are especially large for specialty metals, of which fewer than several thousand tons are extracted around the world each year and can result in supply bottlenecks.

Table 1: Cost structure in Germany's manufacturing industry in 2013 (without mining)

Type of cost	Share in %
Material costs	43.4
Energy costs	2.1
Personnel costs, wage labour and skilled trade services	21.9
Other costs (use of commodities, taxes, depreciation etc.)	32.6
Gross production value without turnover tax	**100.0**

In 2009, the German Federal Ministry for Economic Affairs and Energy commissioned the study "Raw materials for emerging technologies" to provide an overview of particularly promising technologies that are particularly relevant to raw materials. An analysis was made of the impulses that they deliver on the demand for commodities with a time horizon of 24 years.

Results

In this revised edition entitled "Raw materials for emerging technologies 2016", 42 technologies were considered in total, of which 32 were updated and 10 newly selected. Based on these analyses, we constructed scenarios for the raw material demand for these technologies in the year 2035. For the selected technologies, we found that 16 raw materials have particular relevance. In order to be able to better estimate the technology-driven increases in the demand for these raw materials, we used as an indicator the demand for the respective commodity for selected technologies in 2035 related to the total global primary production of this commodity in 2013. Table 2 summarizes the indicator values for the metals that were analyzed in more detail. Figure 2 illustrates the results.

Solely for the analyzed emerging technologies, demand in 2035 could equal or even exceed the primary production in 2013 for five metals: germanium, cobalt, scandium, tantalum, and neodymium/praseodymium. For three further metals, demand in 2035 could even be double that of primary production in 2013: lithium, dysprosium/terbium, and rhenium. For these metals in particular, the increase in demand due to technological change is significantly higher than the increase in demand due to global economic growth.

Where different scenarios yield a range of values when estimating a technology's future raw material demand, we discuss this in the study's individual technology synopses. However, the upper value of this range is used in Table 2 and Figure 2, which provide a summary of all the resources that we examined. Our summarized evaluation therefore represents the uppermost realistic estimate of demand, while it does not deny that even more extreme future developments are possible. The individual chapters on the different technologies (technology synopses) describe which realistic alternative developments exist. Future projections show possible developments in the future. They are based on specific, explicit assumptions and will only occur if the actual development adheres completely to these assumptions. The scenario method allows different assumptions about future development so that developments that actually occur can be captured within this array of projections. Nevertheless, future trends outside these projections are also conceivable.

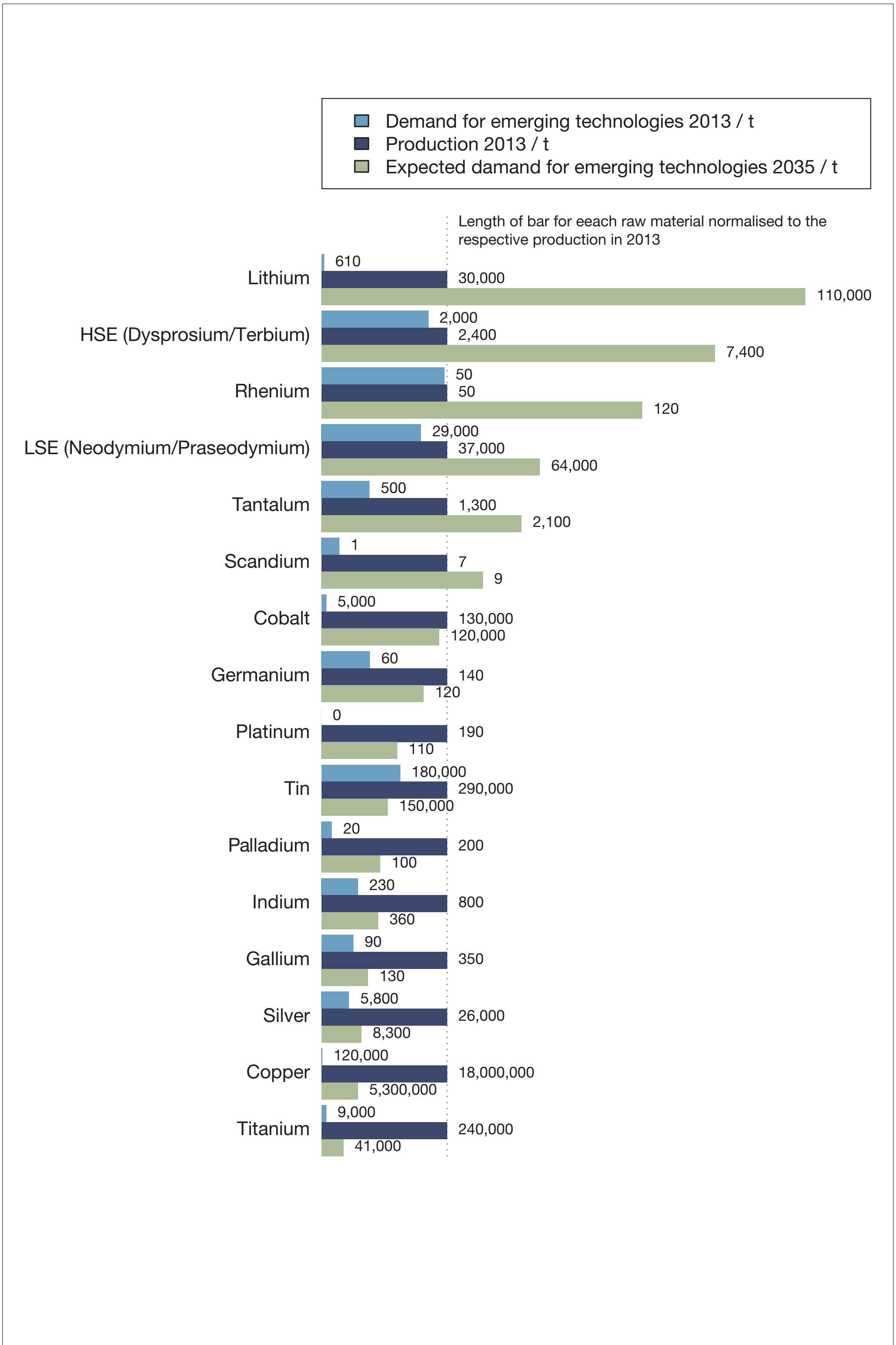


Figure 2: Demand for various raw materials for selected emerging technologies (estimates for 2013 and 2035) compared to primary production of the respective commodity in 2013

Table 2: Global demand for metals for the 42 analyzed technologies in 2013 and 2035 compared to the global production volume of the respective metals in 2013. This does not consider any raw material demand beyond these technologies

Metal	**Demand$_{20xx}$/Production$_{2013}$**		**Emerging technologies**
	2013	**2035**	
Lithium	0.0	3.9	Lithiumion batteries, lightweight airframes
Heavy rare earths (Dy/Tb)	0.9	3.1	Magnets, e-cars, wind power
Rhenium	1.0	2.5	Super alloys
Light rare earths (Nd/Pr)	0.8	1.7	Magnets, e-cars, wind power
Tantalum	0.4	1.6	Microcapacitors, medical technology
Scandium	0.2	1.4	SOFC fuel cells
Cobalt	0.0	0.9	Lithium-ion batteries, XtL.
Germanium	0.4	0.8	Fiber optic, IR technology
Platinum	0.0	0.6	Catalysts, seawater desalination
Tin	0.6	0.5	Transparent electrodes, solders
Palladium	0.1	0.5	Catalysts, seawater desalination
Indium	0.3	0.5	Displays, thin layer photovoltaics
Gallium	0.3	0.4	Thin layer photovoltaics, IC, WLED
Silver	0.2	0.3	RFID
Copper	0.1	0.3	Electric motors, RFID
Titanium	0.0	0.2	Seawater desalination, implants

Note: the results in this table are not comparable with the previous study because they are based on a different period (22 instead of 24 years), a different reference year (2013 instead of 2006), a different technology portfolio (42 instead of 32) and more recent findings concerning innovation dynamics.

Future projections should therefore not be understood as predictions of the actual future development up to the year 2035.

Using scenario-based projections, however, it is possible to estimate which factors (e.g. economic development of technologies and their applications, technology progress, political and infrastructural framework conditions) influence the future development of raw material demand and to what extent. This approach shows market participants the potential opportunities and risks and supports them in making viable, future-oriented decisions.

Market participants include commodity concerns, which require information about the demand markets for their strategic capacity planning. The year 2035 was selected as the time horizon for the projections because mine construction, in particular, can take up to ten years and more. Other market participants include the industries processing the raw materials. It is important for them to have information about competing demands with other sectors and potential commodity supply bottlenecks. If market participants can spot potential surges in demand in advance, this can be used to balance supply and demand and help to stabilize the commodity markets.

Some of the results in Table 2 have changed dramatically compared to the prior study. For instance, the production volumes of individual metals like gallium and scandium have increased. Some technologies manage with lower specific metal contents (LEDs, fuel cells), and substitutes have become widespread at the level of materials and tech-nologies. The data on economic trends have also improved for specific emerging tech-nologies, e.g. in the form of market analyses, triggered among other things by China's export ban of rare earth metals from 2010 to 2015, the transformation of the energy system in Germany (Energiewende) and the economic downturn from 2007 following the financial crisis.

Raw material relevance of the technologies analyzed in detail

Table 4 summarizes the results of the detailed technology analyses. It contains an estimation of the market maturity of individual technologies, the potential demand for raw materials and an assessment of the recycling potential in 2035. Under "Market 2035" the ratio is estimated of the market volume in 2035 to the total expected market potential of the technology. This is rated in three categories: "introduction" (< 25%), "penetration" (25–75%) and "saturation" (> 75%).

The "resource demand 2035" of the respective technology is ranked according to its relation to the global primary production of this resource in 2013: Technologies are characterized as resource-intensive if they are expected to trigger an increase in demand of more than 25% of today's global production of this raw material in at least one bulk metal. Technologies are characterized as resource-sensitive if they bring about an increase in demand of more than 100% of today's global production of this raw material in at least one specialty metal. Specialty metals are resources with a worldwide production of up to several thousand tons per year. In this project's portfolio, these include indium, gallium, germanium, yttrium, scandium, neodymium, tantalum, and the platinum metals. Bulk metals include iron and steel, copper, chrome and tin, among others. According to this definition, technologies can be both resource-intensive and resource-sensitive at the same time.

With regard to recycling, the "recycling potential" distinguishes between fully economically feasible ("yes"), economically feasible to some extent ("limited"), not economically feasible ("no"), and not technically/practically possible ("no, dissipative") because of dissipative losses (such as wear and tear, fine distribution of nano-silver).

The 16 technologies that we have highlighted in colour should definitely be analyzed in detail again. There are different reasons for this depending on the respective technologies:

- a foreseeable high impact on demand for raw materials,
- high innovation dynamics, or
- insufficient data (especially for very novel technologies).

Comparison with the development of raw material extraction over the last 20 years

Table 3 shows compound annual growth rates (CAGR) and overall growth from 1993 to 2013 in the production of different metals. The annual growth rates per year range between 0.7% for titanium and 8.9% for indium.

Correspondingly, production has increased in the 20 years between 1993 and 2013 by a factor of 1.1 for titanium and 5.5 (or 550%) for indium. In the same period, the global economy grew annually by 2.8% on average and thus by a factor of 1.75 over the entire period.

Increases in demand of 100% or more for individual emerging technologies are a major factor influencing the future development of raw material demand. However, this may also be offset by a corresponding expansion of production.

Table 3: Development of global production of selected metals from 1993 to 2013

Metal	CAGR %/a	Growth factor from 1993–2013
Aluminium (R)	4.5	2.4
Iron (M)	5.7	3.0
Germanium (R)	6.2	3.3
Indium (R)	8.9	5.5
Cobalt (M)	8.6	5.2
Copper (M)	3.4	2.0
Copper (R)	3.5	2.0
Lithium (M)	4.8	2.6
Palladium (M)	3.3	1.9
Platinum (M)	1.4	1.3
Rhenium (M)	3.5	2.0
Rare earths (M)	2.8	1.7
Silver (M)	2.8	1.7
Tantalum (M)	6.5	3.5
Titanium (M)	0.7	1.1
Tin (M)	2.2	1.5
Tin (R)	2.6	1.7

M: mined
R: refined production

Tab. 4: Technology analyses - summary of the results. Technologies highlighted in colour should definitely be analyzed again in follow-up studies

	Emerging technology	Chemical elements	Status of technology 2013				Market 2035			Resource demand 2035			Recycling potential 2035			
			Research	Development	Prototype	On the market	Introduction	Penetration	Saturation	non-critical	intensive	sensitive	Yes	Limited	No	No, dissipative
Automobile manufacturing, aerospace, transport technology																
1	Lightweight steel construction with tailored blanks	Al, Mg, Ti		X					X	X			X			
2	Electric traction motors for hybrid, electric and FC cars	Nd, Dy, Pr, Tb (magnets); Cu				X		X			X	X	X			
3	PEM-fuel cells for electric vehicles	Pt		X				X			X		X			
4	Super capacitors for vehicles	Al		X				X		X				X		
5	Alloys for lightweight airframes	Al-Mg-Sc, Al-Li				X		X		X			X			
6	Automatic piloting of road vehicles	Nd, Y, Al			X		X				X			X		
7	Unmanned aircraft for commercial applications	Al-Mg-Sc-Zr (body); Rb, Cs, K (sensors)			X			X		X				X		
Information and communication technology, optical technologies, micro technologies																
8	Lead-free solders	Sn, Ag, Cu, Bi, Zn, In, Ni, Ge, Au, Pt, Sb				X			X		X			X		
9	RFID – Radio Frequency Identification	Ag, Cu, Al (antennas); Si (chips)				X			X	X					X	
10	Indium-tin-oxide (ITO) in display technology	In, Sn, Sb				X			X	X				X		
11	Infrared detectors in night vision equipment	V, Li, Nb, Pb, Ge, La, Sc, Nb, Ta				X		X		X					X	
12	White LED	Ga, In				X		X		X					X	
13	Fiber optic cable	Ge (doping)				X		X		X					X	
14	Microelectronic capacitors	Ta, Nb, Mn, Sb, Ag, Pd, Ni, Ti, Sn, Ba				X			X	X				X		
15	High performance microchips	Ga, As, Ge, Cd, Te				X			X	X					X	

	Emerging technology	Chemical elements	Status of technology 2013				Market 2035			Resource demand 2035			Recycling potential 2035			
			Research	Development	Prototype	On the market	Introduction	Penetration	Saturation	non-critical	intensive	sensitive	Yes	Limited	No	No, dissipative
Energy, electrical and drive technologies																
16	Ultra efficient industrial electric motors	Cu				X			X	X			X			
17	Thermoelectric generators	Te, Sb, Ge, Ag, Bi, Pb, Si, Hf, Zr, Mn, Co, Ni, Fe, Sn, Sb, Ru			X			X			X			X		
18	Dye-sensitized solar cells	Ru (dyes); Ti (carrier); Sn, In, Pt, Ag (electrodes)			X			X		X				X		
19	Thin-layer photovoltaics	Semiconductor: Cu, In, Se, Ga, Te, Cd,				X			X	X				X		
20	Solar thermal power stations	Al, Ag (mirrors)			X			X		X			X			
21	SOFC – Stationary fuel cells	Y, Zr, Sc (solid electrolytes); Y, Zr, Sc, Ni, La, Sr, Mn (electrodes)			X			X			X			X		
22	CCS – Carbon Capture and Storage	Cr, Ni, Co, Mn, Mo, V, Nb (heat-resistant steel)		X				X		X			X			
23	Lithium-ion high performance electricity storage systems for passenger cars	Li; Co, Mn (cathodes)				X		X			X		X			
24	Redox flow batteries for storage	Cr, V			X			X		X			X			
25	Vacuum insulation	Si (core); Al (casing); lead-free solders (windows)		X				X		X				X		
26	Inductive transmission of electrical energy	Cu				X		X		X			X			
27	Thermal storage	K, Na, Li, Ca, Si				X		X		X			X			
28	Micro-energy harvesting of ambient energy	Sb, Se, Sn, Cr, Ti, Cu, Nd, Dy, Co				X			X	X				X		
29	Wind power plants	Nd, Dy, Tb, Pr (magnets/generators); Cu				X		X			X		X			

	Emerging technology	Chemical elements	Status of technology 2013				Market 2035			Resource demand 2035			Recycling potential 2035			
			Research	Development	Prototype	On the market	Introduction	Penetration	Saturation	non-critical	intensive	sensitive	Yes	Limited	No	No, dissipative
Chemical, process and production technology, environmental technology, mechanical engineering																
30	Synthetic fuels	Co, Pt			X			X		X			X			
31	Seawater desalination	Al, Cr, Fe, Mn, Mo, Ni, Pd, Ti, V (stainless steel)				X		X		X			X			
32	Solid state lasers for industrial manufacturing	Nd, Y, Er, Yb (lasers)				X		X		X				X		
33	Nano-silver	Ag				X		X		X						X
Medical engineering																
34	Medical implants	Ti, Co, Cr, Mo				X		X		X				X		
35	Medical tomography	Gd (sensors, contrast mediums)				X		X		X			X			
Materials technology																
36	Superalloys	Ni, Co, Cr, Mo, W, Re, Ta, Nb, Hf				X		X			X		X			
37	High-temperature superconductors	Y, Bi, Tl, Hg, Sr, Ba, Ca, Cu			X			X		X			X			
38	High-performance permanent magnets	Nd, Dy, Tb, Pr				X		X			X			X		
39	Industry 4.0	Li, La, Sc, Nb, Ta, Ge, Pb (sensors)		X				X			X		X			
40	Carbon fiber reinforced plastics	*Potential reduction of global steel demand*				X		X			X			X		
41	CNT (carbon nanotubes)	*Potential reduction of global metal demand*	X					X		X					X	
42	Additive production („3D printer“)	Cu (electric motors)				X		X		X			X			

Emerging technologies can also reduce demand for metallic raw materials. Composite materials demonstrate this: For instance, the use of carbon fiber reinforced plastics (CFRP) can reduce the demand for steel in automobile manufacturing.

It is intrinsic to innovations that they may occur at any time without warning and may radically change the estimates in Table 2 and Figure 2. These estimates may trend towards higher or lower demand.

Conclusions

The main objective of this study is twofold: first, to identify relevant fields of technology and raw materials in order to motivate follow-up studies that explore the challenges facing individual technologies and raw materials more; second, to develop or further advance the strategies to ensure the supply of raw materials.

We have pointed out specific actions and alternative development possibilities in the individual technology analyses and scenarios.

In general, the following measures may be considered to ensure the supply of raw materials to industry:

- expansion and improved efficiency of ore mining or metal extraction,
- substitutions at the level of materials and tecnologies,
- resource efficiency in production and use,
- recycling, ensured by recyclable designs, recirculation strategies and efficient recycling technologies.

Numerous research papers dealing with the criticality of raw materials have studied how important it is to have measures in place that ensure supplies of individual raw materials. This study indicates the relevance of raw materials to emerging technologies; this relevance is an important aspect that should be taken into account in such studies.

When developing new technologies, existing options to ensure the supply of raw materials should be an integral part of the basic planning considerations. At present, especially for costly specialty metals, substitution and resource efficiency is already researched in an early phase of development. This is because it results in direct economic advantages. The economic benefits of recycling seem less obvious; as a result recyclable design, recirculation strategies, and efficient recycling technologies are rarely considered when developing new technologies. Policy measures can help to ensure that forward-looking enterprises benefit and that resource supplies for the economy as a whole are secured in the best possible way.

Current commodity prices are dependent on many factors such as temporary discrepancies between supply and demand. However, they are also influenced by shortterm speculation and political restrictions. Thus prices are not a measure of the longterm physical or economic availability of a commodity. Therefore they should not form the sole basis for longterm decisions with future relevance. In fact, we conclude that the German economy should endeavor to reduce its dependency on international commodity markets by fully exploiting all the available options, like substitution, resource efficiency, and recycling, and should diversify its supply sources.

German Mineral
Resources Agency
Federal Institute for Geosciences and Natural Resources

German Mineral Resources Agency
at the Federal Institute for Geosciences and Natural Resources (BGR)

Wilhelmstraße 25 – 30
13593 Berlin/Germany
Tel.: +49 30 36993 226
dera@bgr.de
www.deutsche-rohstoffagentur.de

ISSN: 2193-5319