Raw materials of strategic economic importance for high-tech made in Germany

BMBF research and development programme for new raw material technologies
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Foreword

Securing prosperity, economic development and the sustainable use of natural resources requires considerable social efforts. With its sustainability strategy, the transformation of its energy system and the “German Resource Efficiency Programme”, Germany is taking on the role of global leader. Emerging technologies in particular tend to be based on natural resources, such as metallic raw materials, a large proportion of which Germany has to import. International cooperation and research and development thus form important elements in the Federal Government’s strategy to secure a sustainable supply of raw materials for Germany.

With the Helmholtz Institute Freiberg for Resource Technology founded in 2011 we have taken a first step toward the expansion of our research into raw material technologies. Further, over the next few years the existing new research and development programme “Raw materials of strategic economic importance for high-tech made in Germany” should specifically strengthen research and development into environmentally safe and resource-conserving technologies. The recovery of metallic secondary raw materials through recycling, and the environmentally-friendly and efficient extraction of primary raw materials, are integral components of the programme’s objectives.

The programme “Raw materials of strategic economic importance for high-tech made in Germany” forms part of the “Research for sustainable development – FONA” framework programme. The aim of this framework programme is to consolidate and enhance Germany’s position as an international leader in technology in the fields of climate change, sustainable resource management and innovative environmental and energy technologies.

I would like to thank the members of the “Programme Advisory Committee for Resource Technologies” for their work on drawing up the present recommendations. The new programme provides a pioneering contribution to achieving our research policy goals.

Prof. Dr. Johanna Wanka
Federal Minister of Education and Research
Within the “BMBF Programme Advisory Committee for Resource Technologies” are represented experts drawn from Germany’s leading technical universities and non-university research institutions in the field of value creation in non-energy raw materials. The members were appointed by the BMBF in order to bring external expertise to the programme and to advise the BMBF on the direction of future funding measures. The Programme Advisory Committee began work in April 2011 with its inaugural meeting, subsequently analysing both the current research landscape and the future needs of Germany’s high-tech industry with regard to technologies for raw materials of strategic economic importance, on which were based the research needs and the recommendations for further implementation. These analyses and recommendations lead into the BMBF’s present research and development programme for new raw material technologies.
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Foreword

Members of the BMBF Programme Advisory Committee for Resource Technologies

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Summary

As an industrial nation, Germany owes its prosperity to the production of goods and to exports. A reliable supply of raw materials – primarily non-energy mineral resources – is needed in order to secure this prosperity. They are needed to develop and grow emerging technologies, but also to achieve our ambitions in terms of climate change goals and to accelerate the transformation of our energy system. Germany is heavily dependent on imports for these so-called high-technology raw materials. Numerous studies over the past few years have therefore considered what raw material demand tomorrow’s technologies will entail and what supply risks may confront us. Individual mineral elements, or groups of materials such as the platinum group metals, rare earths and other high-tech metals, have therefore been analysed. Given the background of rising raw material prices, the results of these studies are becoming increasingly important.

Government initiatives for greater resource efficiency

Mineral resources are finite and expensive, and their efficient utilisation thus becomes ever more important. The Federal Government is engaged in several programmes addressing the matter of resource efficiency.

Through the high-tech strategy action plan Germany is keen to develop sustainable solutions to these global challenges. Research, new technologies and the wider application of innovative approaches should facilitate the economic and efficient use of resources, as called for in the climate and energy demand areas of the high-tech strategy action plan. The National Sustainability Strategy has the objective of doubling the productivity of raw material compared to 1994 levels by 2020. In order to secure the supply of non-energy mineral raw materials, at the suggestion of the Federal Ministry of Economics and Technology (BMWi) the Federal Government additionally adopted the Raw Materials Strategy in October 2010. This spans a wide range of topics, from the breaking down of trade barriers through the development of technology, education and knowledge transfer, through to development cooperation. The Federal Government’s German Resource Efficiency Programme (ProgRess) sets out 20 approaches for

In parallel with German activities, a Raw Material Strategy is also being developed at European level. Part of the European Commission’s Europe 2020 strategy, the flagship initiative “A Resource efficient Europe” aims to underpin the switch to a resource-efficient economy, secure supply of vital resources and create new opportunities for growth and innovation.

Germany’s research landscape

Research capabilities in Germany are concentrated in several scientific institutions. These include the non-university research facilities of the Helmholtz Association, the Fraunhofer Society and the Federal Institute for Geosciences and Natural Resources (BGR), together with the Technical Universities / Universities at Aachen, Clausthal and Freiberg. Freiberg is the oldest mining science university in the world. The three universities mentioned are the only ones in Germany where the overall material cycle and complete value chain of non-energy mineral raw materials are researched and investigated – from mineral deposit right through to recycling. Other higher education establishments provide research and education skills in the area of materials research and the individual steps in the value chain. Funded by the BMBF and the Land Saxony, the Helmholtz Institute Freiberg for Resource Technology was also founded in August 2011 and in the long term will strengthen research in the value chain of mineral raw materials.

Programme goals and content

The aim of the “Raw materials of strategic economic importance for high-tech made in Germany” programme is to expand research, development and education along the value chain of non-energy mineral raw materials over the next five to ten years. Directed toward universities, non-university research facilities and enterprises in the industrial sector, it has the objective of strengthening applied research and its links to basic research.
From 2013 the BMBF will therefore incrementally promote particular topics considering individual parts of, or the whole, value chain. The programme is designed to be non-technology-specific and will be further developed jointly with the research and business worlds; progress in national and European resources policy will be taken into account alongside the needs of the economic and scientific communities. This will tie it directly into the national and European Raw Materials Strategy.

At the focus of the programme are those metals and minerals whose availability must be secured for our emerging technologies and which have a major effect on the economy (“raw materials of strategic economic importance”). Raw materials for construction and marine mineral raw materials are not in the programme. Common metals are discussed only if they arise as a by-product in the extraction of primary and secondary raw materials or if a considerable improvement in raw material efficiency can be expected.

**Research needs in the primary and secondary raw materials sector**

How can the availability of raw materials of strategic economic importance be secured for German industry? In the BMBF’s view, the highest priorities for research and development lie in two areas – the exploration and extraction of primary raw materials, and the obtaining of secondary raw materials through recycling.

Research is needed in all key stages of the raw material value chain for primary raw materials and their exploration:

- for exploration (new exploration methods, such as for domestic raw material potentials)
- for mining (energy- and material-efficient extraction methods)
- for processing (optimised crushing and sorting processes to increase productivity and reduce energy input)
- for metallurgy (new efficient extraction processes for high-tech metals)

Research is also needed for wide-ranging topics: thus for example the integrated study of geology, mining, processing and metallurgy should enable optimisation of the value chain over several stages (geometallurgy). The value-chain-spanning areas for research in the extractive industries and resource analysis provide starting points for new research projects as well as the ecological, social and political aspects of the global raw materials economy.

Non-energy mineral recyclables are important to the German economy. They are found in our waste and production residues, although often in only low concentrations so that their recovery presents a challenge.

In terms of secondary raw materials and recycling, research is needed on the following topics:

- on material flows and potentials (data basis for secondary raw material sources, detection systems, specific material flow management, product design)
- on processing and separation (material separation while largely preserving the originally intended material properties, or the breaking-down into base materials)
- on metallurgical extraction and purification (flexible processes with maximised recovery rates for multi-metal systems and improved separation at the elementary or molecular level)
- on evaluation (objective comparison of alternative recycling technologies and approaches to eco-balance, economic and other aspects)
Measures for programme implementation

The “Raw materials of strategic economic importance for high-tech made in Germany” programme is built on current funding measures in the following framework programmes:

- FONA – Forschung für Nachhaltige Entwicklungen (Research for Sustainable Development)
- WING – Werkstoffinnovationen für Industrie und Gesellschaft (Materials Innovations for Industry and Society)
- “Research for the Production of Tomorrow” programme

and the cross-programme SME Innovative funding initiative: Resource and Energy Efficiency.

The initial priority is on measures which will allow the domestic provision of raw materials of strategic economic importance to be increased and which supplement existing work on material and product innovation and on improving material efficiency.

Associated measures should additionally interlink and raise the profile of German raw materials research internationally, improve the acceptability of domestic raw materials extraction and strengthen education and training in this field. The exchange of knowledge and development of raw materials partnerships are underpinned by bilateral research cooperation with countries rich in raw materials. The programme also pursues the goal of strengthening Germany as a location for science. To this end, existing collaborations should be further developed and opportunities for education at universities increased. Topics of European significance are addressed within the context of European collaboration.
1 Introduction

1.1 The importance of raw materials of strategic economic importance for high-tech made in Germany

Raw material demand

Since the fifties, demand for resources in industrialised countries has risen tremendously, and this development can now also be seen in the emerging developing and newly industrialised countries such as China. The last 50 years have seen the consumption of more raw materials worldwide than in the entire previous history of mankind. Consumption of raw materials is continuing to rise despite every effort to increase productivity of resources. We now live in a world in which product cycles are becoming ever shorter and the products of our industry, particularly of the electronics industry, are becoming ever more complex. In the eighties, twelve different chemical elements were needed to make a computer chip; in the nineties, this figure rose to 16. Today, a high-performance chip demands more than 60 elements, substantiated by an often-cited raw materials study by the US National Research Council (NRC 2008). The picture in the automotive industry is similar: where a car previously comprised essentially iron, steel, copper, aluminium, lead, zinc, rubber, plastics and glass, today it is a high-tech product embodying a wide range of electronic components. The car of the future will also need a wide range of elements, such as rare earths for permanent magnets in the auxiliary and drive engines or alloying elements in the steel.

The raw materials cycle along the value chain and product lifecycle is illustrated schematically in Figure 1.

![Figure 1: Cycle of raw materials and waste (Faulstich 2010).](image-url)
**Raw material imports**

Germany has a strong manufacturing industry and is a highly successful exporter. Premium technological products such as cars have allowed the German economy to emerge surprisingly quickly from the economic and financial crisis of 2008/09. Almost 25% of the gross domestic product (GDP) of around EUR 2,500 billion in 2010 continues to be generated by the manufacturing sector (excluding construction). This puts Germany well ahead of the other major European countries such as France, Italy or even the UK where the proportion comprised by manufacturing industry is only half as much as here.

The German economy needs both primary and secondary raw materials to manufacture its premium products. Secondary raw materials are in fact available at home, but high-tech metals in particular are not currently being adequately exploited. Germany is heavily dependent on imports of primary raw materials; virtually all metallic raw materials must be imported. Importing raw materials costs the German economy around 4.4% of GDP – in 2010, EUR 109.3 billion. Of this, almost two thirds is accounted for by energy and around one third by metallic raw materials, including in particular iron, steel and common non-ferrous metals (see Figure 2). Steel stabilisers including refractory metals, metals for the electronics industry and other high-tech raw materials such as rare earths or platinum group elements account for around 9% of the imported raw materials value. These are the raw materials needed to manufacture premium products. In short: we use less than 0.5% of our GDP for these raw materials of strategic economic importance, despite the fact that the leverage they give could quickly lead our national economy out of recession and ensure the country’s prosperity.

In the first decade of this millennium global raw material supply experienced a fundamental change. Almost right up to the end of the last millennium, we lived in a world in which 25% of the world’s population – those in the industrialised countries – required 70% to 80% of the world’s raw materials production. Then, however, began the meteoric rise in consumption of raw materials in the densely-populated developing countries, primarily the People’s Republic of China. China’s share of global steel consumption in 1990 was just 8%; by 2010 it was 45%. Demand for other metals also climbed dramatically; use of copper rose from 6% to 39% and of aluminium from 5% to 40%. Today, China is the largest market for all the major raw materials excepting crude oil and natural gas. The People’s Republic is second only to the leader, the USA.

Demand for raw materials of strategic economic importance is also rising – and with it, competition for them. Clear potential in the extraction of these raw materials however exists, as can be seen in Figure 3.

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**Figure 2: Raw materials of strategic economic importance in the raw materials import balance for Germany 2010 (source: BGR / DERA, amended).**

![Imports in 2010 EUR 109.3 billion](image-url)
INTRODUCTION

The "metal wheel" depicted shows the spectrum of major metals, by-metals and coupled metals and how they are connected. Coupled metals do not occur in their own deposits, but are to be found in nature only together with major metals.

The inner ring shows the major metals, towards which mining and iron and steel operations are primarily geared. Moving outwards from this are the by-metals linked to the respective major metals.

In the next outer ring are those by-metals which are almost without exception extracted with them. Mining, iron and steel operations are also configured to handle these metals. Moving outwards again are the minor elements, for the extraction of which only limited infrastructure exists. Yet these are in many cases valuable metals, important to electronics for example. The outermost ring shows the elements that are not generally extracted. They remain in processing waste, residues or slag.

Elements belonging to the fourteen raw materials or raw material families classified as critical by the EU in 2010 – referred to as the "EU-14" – are circled. The diagram shows that these critical raw materials are concentrated in the two outer rings. There is thus considerable scope for improving the extraction rate for these raw materials. They can be grouped under the non-technology-specific heading of "raw materials of strategic economic importance". The term is more comprehensive than the EU-14 list, although it only refers to Germany.

A study commissioned by the KfW Banking Group shows that from the perspective of German companies, additional raw materials should also be considered as critical (Erdmann et al. 2011).
Raw material demand and pricing

Changing demand led to sharp price rises for a number of raw materials, this development being only briefly interrupted by the 2008 financial crisis. Compared with price levels at the end of 2002/beginning of 2003, the price of lead rose eightfold, nickel for a time as high as sixfold, zinc and copper prices fivefold and crude oil fourfold. Export restrictions in some producer and export countries coupled with speculation in the financial markets resulted in further price spikes.

Where prices move abnormally like this, the raw material supply control loop kicks in (see Figure 4). Industry reacts to both supply and demand side, so that after a time increased supply and reduced demand achieve a new equilibrium: on the supply side due to increased production in both primary and secondary raw materials sectors, and on the demand side due to substitution measures in the widest sense.

In this control loop, the State supports industry activities with associated measures, examples being raw materials policy funding instruments, raw materials foreign policy and support for research. The Federal Government is therefore promoting leading-edge technologies as part of the high-tech strategy action plan to increase resource efficiency (see Section 2.2.).

Figure 4: The control loop in raw materials supply (Wellmer/BGR).
1.2 Political initiatives in Germany, Europe and worldwide

German initiatives

The market-based principle in force states that the purpose of the economy is to supply industry with raw materials; the State must, however, set the requisite framework conditions for this, including an effective research infrastructure. In accordance with this principle, in 2007 the Federal Government developed elements of a raw materials strategy based on an intensive dialogue between the commercial and political sectors. The Federal Government’s Raw Materials Strategy was adopted in 2010, under which the Federal Government will for example:

• improve access to raw materials and diversify sources of supply
• promote innovations through raw materials research and development
• establish raw material partnerships
• implement structural measures, for example the founding of the German Mineral Resources Agency at the Federal Institute for Geosciences and Natural Resources or the setting up of an Interministerial Committee on Raw Materials
• promote the education and training of foreign executive and specialised personnel
• create close integration with the EU Raw Materials Initiative

The Interministerial Committee (IMA) on Raw Materials under the lead responsibility of the Federal Ministry of Economics and Technology (BMWi) coordinates the Federal Government’s activities in raw materials policy. The Federation of German Industries (BDI) is also active on the Committee, consolidating the interests of the industry.

Through raw material partnerships, the German Federal Government aims to support partner countries in sustainable economic and social development. The partnerships should at the same time contribute toward raw material supply to the German economy. The first partnership agreements were signed with Mongolia and Kazakhstan; others are in preparation. The raw materials activities of the economy are thus backed and supported by the State.

German industry also backs collaboration: With the “Allianz zur Rohstoffsicherung” (alliance for raw materials access) – a concerted raw materials initiative – it is keen to promote the collaboration of German companies in raw materials procurement, thus securing supply.

With the National Masterplan for Maritime Technologies published in July 2011, the BMWi also aims to drive forward the extraction of marine mineral raw materials.

Back in April 2002, the Federal Government determined the National Sustainability Strategy “Perspectives for Germany”. One of the strategy’s aims is to double raw materials productivity, measured against 1994 levels, in Germany by 2020 via a sustainable raw materials economy. This should decouple economic growth from raw material consumption. Overall, raw materials productivity is developing in the intended direction, but unfortunately far too slowly. Only through so-called “leaps in efficiency” can the goal of the sustainability strategy still be achieved. The BMBF accordingly supports research and development in this area, for example through funding R&D projects with industry participation in the r² and r³ funding priorities (see Section 2.2) or through funding of the Helmholtz Institute Freiberg for Resource Technology.

At the initiative of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), the German Resource Efficiency Programme (ProgRess) was adopted by the Federal Government in February 2012. The Programme sets out 20 approaches for the sustainable use of abiotic, non-energy raw materials such as ores, minerals for industry and construction and the material use of biotic raw materials. Research and the expansion of the knowledge base perform a key function in this.

It is vital to improve the recycling of metal and mineral raw materials; an aspect the Council for Sustainable Development (RNE) promoted in June 2011 in its recommendations to the Federal Government. If we wish to double raw materials productivity, better use of secondary raw materials must also contribute.
The recommendations were published by the RNE under the title “Wie Deutschland zum Rohstoffland wird” (How to turn Germany into a raw material country).

With the Internationalisation Strategy for Science and Research adopted in 2008, the Federal Government responded to the challenges that globalisation poses, such as climate change and resources consumption. Specific approaches for the Federal Ministry of Education and Research include strengthened strategic collaborations with international partners as part of scientific-technical cooperation, and the shaping of, and coherent networking with, European initiatives.

**European initiatives**

At European level, the EU Raw Materials Initiative of 2008 put the subject of raw materials access onto the political agenda. The initiative should progress development of a joint European raw materials strategy (COM (2008) 699).

The EU raw materials initiative is based on three pillars:

- access to raw materials should be via international markets, with a level playing field for industrial competitors
- sustainable supply of raw materials should be promoted within the EU
- resource efficiency and recycling should be increased

Within the framework of this initiative, a working group identified 14 raw materials as “critical” for the EU (the EU-14) with respect to their economic importance and supply risks (European Commission 2010, see also Figure 3, page 7).

Strategic measures to secure the supply of raw materials were announced by the European Commission at the beginning of 2011 in the strategy paper on the raw materials initiative (COM (2011) 25).

The strategy contains the following core elements:

- the list of raw materials critical for the EU is regularly updated
- bilateral collaboration with African countries is established
- the regulatory framework for the sustainable extraction of raw materials in the EU is improved
- research and innovation for the entire raw material value chain are promoted

In June 2011, the European Parliament published a report on a successful raw materials strategy for Europe. In this report the Parliament calls for “the setting of clear targets in the allocation of means for research on raw materials such as rare-earth metals, such as for example setting Japan the target of lowering consumption of rare-earth metals by one third” (European Parliament 2011).

Strategies and measures for the supply of raw materials are incorporated in the Europe 2020 strategy which is defined by various flagship initiatives. The Innovation Union flagship initiative proposes the setting-up of a European Innovation Partnership (EIP) for sustainable supply with non-energy raw materials for a modern society.

A further flagship initiative on the topic of Resource Efficient Europe pursues the goal of a resource-efficient and low-carbon European economy. To achieve this, the use of resources must be reduced and the supply of essential resources secured. It also deals with managing new opportunities for growth and innovation and keeping the environmental impacts of the use of resources to a minimum (COM (2011) 21).

In September 2011, the EU Commission presented its road map for a resource-efficient Europe and the remodelling of the European economy by 2050. Clearly defined targets and transparent indicators for resource consumption are to be developed by 2013.

If we wish to conserve resources, efficient use of natural resources such as metals and minerals will contribute significantly. The raw materials initiative already mentioned, national implementation of EU waste legislation and the transition towards a sustainable material or recycling economy mean that we can expect progress in this. Research and innovation can also increase resource productivity. Research funding from the new European Horizon 2020 Framework Programme for Research and Innovation should therefore be used to pursue the key targets of resource...
efficiency. This should lead to greater knowledge of raw material availability and should promote sustainable supply and utilisation of raw materials, including in exploration, extraction, processing, substitution, recycling and recovery.

The Horizon 2020 Programme succeeds the 7th Research Framework Programme in 2014 (COM (2011) 571). As part of Horizon 2020 the European Institute of Innovation and Technology (EIT) is to be expanded in 2014, with a Knowledge and Innovation Community (KIC) looking at raw materials right through the value chain. Bringing companies together with excellent higher education institutions and research centres should result in improved competitiveness for the member states.

The EU is already promoting projects for sustainable raw materials supply within the 7th Research Framework Programme. The focus is on innovative concepts and processes for extracting high-grade mineral products (ProMine) and for seeking out raw material resources (Eurogeosource, OneGeology), as well as strategies and technologies for the extraction and processing of raw materials and for reducing the ecological footprint (EO-Miners, Impactmine). German companies, research institutions and authorities are also collaborating on these research projects.

ETP-SMR, the European Technology Platform on Sustainable Mineral Resources, has been set up to define research priorities and initiate corresponding partnerships. European companies provide the driving force behind this platform, involving geology companies, associations and research institutions.

The remit of the ERA-Net Industrial Handling of Raw Materials for European Industries (ERA-MIN), launched in November 2011 with France (CNRS) as lead agency, is to coordinate national R&D activities in mining, recycling and substitution of non-energy raw materials, such as minerals for construction and industry and metal raw materials. In addition to Germany and France, to date Finland, Greece, the Netherlands, Poland, Portugal, Romania, Sweden, Spain and Hungary are represented in this ERA-Net. United Kingdom, Italy and Moldavia are associated partners, and further partner countries are expected to join. It is also planned that the Helmholtz Institute Freiberg for Resource Technology will participate in the stakeholder forum. The ERA-Net should structure and interlink the European non-energy raw materials research community within the EU 27. Included should be every institution, national strategy and funding programme in the raw materials sector of participating countries. In addition, international collaboration opportunities with industrialised countries such as Japan, the USA and Canada and developing countries are identified.

Global initiatives

In 2007, the UNEP International Resource Panel was founded under the umbrella of the United Nations Environment Programme. The main role of the Panel is to provide independent scientific analyses that tackle the sustainable use of natural resources and their environmental impact right through the lifecycle. The panel should provide better understanding of how it is possible to decouple economic growth, resource consumption and environmental pollution.

1.3 Aims of the programme

The aim of the “Raw materials of strategic economic importance for high-tech made in Germany” programme is to expand research and development along the value chain of non-energy mineral raw materials. The time horizon for this is five to ten years. Directed toward universities, non-university research facilities and enterprises in the industrial sector, the programme has the objective of strengthening applied research as far as demonstration scale, and its links to basic research. Education and training on resource technologies are implemented as associated measures.

The programme concentrates on the metals and industrial minerals that have particular economic leverage and the availability of which must be secured for our future technologies. We can currently observe a rapid change concerning the number and quality of, and demand for, raw materials for high-tech products. The programme is therefore designed to be non-technology-specific with respect to the selection of raw materials. Marine mineral raw materials, where covered by the BMWi’s National Masterplan for Maritime Technologies, or mineral raw materials for construction are not covered by the programme. Common metals in the non-ferrous metal range are addressed insofar as they have to be considered in the extraction of by-products and elements and in the processing of secondary raw materials. They are also
themselves the object of the programme where significant improvements to raw material efficiency are to be expected in extraction, production, or in the product itself.

From 2013 particular topics considering individual parts of, or the whole, value chain are to be incrementally promoted. In the first step the focus is on the supply side, for both primary and secondary raw materials. This concerns research into and testing of methods that can be used to locate and utilise the raw materials required by German enterprises. Research should also be conducted into how the recycling of raw materials of strategic economic importance can be improved. Close links will exist between the raw materials strategy of the Federal Government and the European Commission.

The following chapters will look at the most important German research capabilities in the field of resource technologies and describe the European and international research environment. Starting with an analysis of the research landscape and current research priorities, the future demand for research and development on the basis of the recommendations of the Programme Advisory Committee for Resource Technologies, and measures for implementation, will then be described.
Industry undertakes vital research in the field of resource technologies. This research pursues economic interests and is predominantly handled confidentially. Support is provided to industry through publically funded R&D collaborative projects in cooperation with higher education and research institutions. Accordingly, the information in this section is limited to the most important higher education and public research institutions in Germany.

2.1 Higher education and research institutions

German research capabilities in the field of resource technologies are described below. Alongside the non-university research institutions, the Technical Universities / Universities at Aachen, Clausthal and Freiberg are in particular highlighted as the only higher education institutions in Germany in which the complete value chain is represented in research and teaching. Although research and training expertise is also available at other higher education facilities, for example on materials research or individual stages in the value chain, for reasons of clarity these are not looked at in greater detail.

Faculties at universities and centres of excellence

- Geosciences
- Mineral Resources Engineering
- Metallurgy and Materials Engineering

University locations:
- Geology (Mineral Deposits Research College)
- Metallurgy / Materials Engineering
- Mining / Mineral Resources Engineering

Non-university locations:
- Raw Materials Research Centre
- Metallurgy / Materials Research Centre

Figure 5: Major research and training centres in the resource technologies value chain in Germany (source: RWTH Aachen University, supplemented).
The Helmholtz Institute Freiberg for Resource Technology was founded in August 2011, with funding from the BMBF and the Land Saxony, to strengthen research into the mineral resources value chain in the long term. The new Helmholtz Institute, supported by the Helmholtz Centre Dresden-Rossendorf (HZDR) and the TU Bergakademie Freiberg, will in the next five years provide a hub at the Helmholtz Association for research into exploration, extraction, processing, substitution of materials, and the recycling of non-energy mineral resources.

**German Mineral Resources Agency at the Federal Institute for Geosciences and Natural Resources**

The Federal Institute for Geosciences and Natural Resources (BGR) is a Federal Government interdepartmental research institution coming under the portfolio of the Federal Ministry of Economics and Technology (BMWi). As the Federal Government’s central geoscientific advisory agency, it advises and informs research-based policy and economic matters on all raw material-related issues of a geoscientific and economic nature. The Agency works toward the economically and ecologically sustainable utilisation and security of natural resources and thus serves the public interest. There are currently 41 scientific and 31 non-scientific members of staff in the mineral resources area. The German Mineral Resources Agency (DERA), set up in October 2010 in the BGR, is the central interface and advisory platform in the extractive industries sector for the German economy as well as for policy and the public. It transfers the BGR’s expertise, using its scientific-technical infrastructure to provide advice on raw materials.

**DERA’s mission:**

- The raw materials information and early warning system provides up-to-date and regular raw material-related information and analyses for the economy. DERA thus improves transparency on commodities markets and provides important bases for economic decision-making.
- DERA assesses the potential of raw materials, possible alternative or new supply sources for exploration and mining projects, projects at the first processing stage, and possible applications of co-materials and residues. It supports enterprises’ participation in exploration and extraction projects and in the application of efficient processes for raw material extraction and processing and the use of co-substances and residues.
- DERA advises and supports the German economy by reducing raw materials supply risks and diversifying sources of supply. Geostrategic safety issues and environmental aspects are considered at the same time.
- DERA supports the Federal Government’s raw materials partnerships with countries rich in raw materials. This helps both to secure raw materials supply for the German economy and to support developing and emerging countries in the sustainable use of their raw materials potential and their integration into the international extractive industries.
- DERA offers specialised support for the Federal Government’s raw materials support programmes in the fields of raw materials exploration, extraction and import. With the “Untied Financial Loan (UFK)” programme and the planned “Raw Material Exploration Support” programme, the Federal Government is supporting the German economy with raw materials projects that merit assistance or are of particular interest to the Federal Republic of Germany abroad.
- On behalf of the BMWi, DERA organises the competition to award the German Raw Material Efficiency Prize. It supports national raw material efficiency programmes with the focus on consultancy and on the transfer into the economy of the results of research and development.
The core focus of DERA lies on the assessment of global raw materials availability, evaluating Germany’s security of supply of raw materials and determining raw material and mining potential. In order for the Raw Materials Agency to be able to react flexibly and with foresight to changing market situations and to the needs of the economy, it looks at all raw materials groups (metals, industrial minerals, raw materials for construction and for energy), both worldwide and in Germany. Because of Germany’s reliance on imports, the priority of DERA activities is first and foremost the metallic and high-tech raw materials.

In order to ensure DERA’s specialised advisory competence on the state of science and technology, the BGR undertakes research and development projects at the leading edge of industrial activities. The priority in this is the investigation of new raw material potential and the development of raw material and mining tools and methods. Building on the BGR’s specialist expertise in the areas of mineral deposit and marine research and in the extractive and mining industries, selected new approaches or projects for the extractive industries are prepared and handled in collaboration with industry. The BGR thus undertakes geoscientific survey work on the viability of raw materials in regions that have to date been little explored, with the results potentially providing the industry with approaches to targeted projects in the raw materials field. Examples of such projects are an R&D project on the investigation and economic/geological assessment of selected deposits, the development of alternative extraction methods and production technologies, increasing the efficiency potential in primary extraction, the certification of raw material trading chains and the analytical traceability of mineral resources. Other priority topics are raw material potentials in mining and industrial waste, biomining, marine/deep-sea mining and innovative deposit concepts, particularly for high-tech metals. The investigation and assessment of marine mineral resources – particularly manganese nodules and marine polymetallic sulphide mineralisations – play an important role here.

**Helmholtz Association of German Research Centres**

The Helmholtz Association of German Research Centres (HGF) addresses questions of long-term social and economic policy and with its research results creates a vital technology base for a competitive German economy. With almost 33,000 employees working at 18 research centres, it is the largest science organisation in Germany. Current research fields are energy, Earth and environment, health, aeronautics, space travel and transport, key technologies and the structure of matter. Ties with resource technology research are presently being developed mainly in the research fields of key technologies, energy and Earth and environment. In the structure of matter, ties exist only with respect to material research and optimisation for very special purposes, for example for nanowires, superconductivity or high-temperature materials.

The key technologies area looks at those technologies that promise new methods and innovative solutions for the challenges in the fields of research at the Helmholtz Association or with which industry can benefit through timely use of large research-specific infrastructure for that area of research. Resource technologies studies to date have focussed predominantly on application-oriented material questions in the “Advanced engineering materials, fundamentals for future information technologies” and “NANOMICRO: Science, Technology, Systems” research programmes.

- **Functional materials**
  This relates particularly to developing cost-efficient, ecological and sustainable materials, for example for use in medicine. Minerals and metals of strategic economic importance play an important role here; for example, manufacturing biomedical applications from magnesium requires additives such as silver, yttrium, gadolinium, cerium, lanthanum or neodymium. The Helmholtz Centre at Geesthacht is lead agency for these topics in the HGF.
One goal of the LIMTECH (Liquid Metal Technologies) Helmholtz Alliance, established mid-2012 under the lead agency of the Helmholtz Centre Dresden-Rossendorf, is to increase the energy and resource efficiency of liquid metal technologies, for example when casting metals, separating precious metals from slag smelt or manufacturing solar silicon.

The Earth and environment field of research studies the fundamental functions of the Earth’s systems and the interactions between society and nature, thereby creating a sound knowledge base for securing the long-term foundations of human life in a sustainable way. The German Research Centre for Geosciences (GFZ) in Potsdam focusses on the geological, physical, chemical and biological processes of the Earth’s systems. The research work is organised in departments such as geodesy, remote sensing or the physics of the Earth.

The Alfred Wegener Institute for Polar and Marine Research (AWI) and GEOMAR also have infrastructures and expertise that can be employed for research into resource technology, for example for studying deposits at great depths and for recovering marine raw materials such as polymetallic manganese nodules and crusts. In so doing, ecological and socioeconomic effects must be factored in and thus the Helmholtz Centre for Environmental Research, which studies the complex interactions between man and the environment in cultivated and damaged landscapes, is involved in the activities.

Research into the demand-side use of raw materials is thus currently the prime focus at the Helmholtz Association, particularly with regard to the substitution or replacement of these materials through more efficient process and product designs. The recently founded Helmholtz Institute Freiberg for Resource Technology (HIF) is extending the Helmholtz Association’s research profile by focusing on the supply side.

The aim of the energy field of research is to develop ecologically and economically acceptable solutions that can sustainably secure energy supply. The “Renewable Energies” research programme looks particularly at providing basic and application-oriented research in order to more efficiently structure currently employed technologies in terms of raw materials. An example of this is the development of thin-film solar cells at the Helmholtz Centres in Berlin and Geesthacht which should reduce the consumption of metals such as copper, indium or gallium. Transparent conducting oxides, also used in photovoltaics, can be structured more efficiently in terms of their indium consumption, and backing reflectors or contacts in terms of their silver consumption. Material costs could therefore be reduced in the long term for photovoltaic applications, and jobs retained. Processes in which the weight of components is reduced – for example thin-film solar cells – can also find application in other areas such as solar-thermal power, wind power or electric mobility.

The “NANOMICRO” programme ties in with resource technology, primarily in the development of technologies for energy storage. The newly founded Helmholtz Institute Ulm for Electrochemical Energy Storage together with the Karlsruhe Institute of Technology is studying current forms of energy storage, such as lithium ion battery technology, as well as future nano forms. Nanocrystalline metals are also being investigated at the Karlsruhe Institute of Technology, for example with regard to their plasticity. At the forefront here is the analysis of deformation mechanisms and conditions and of alloy compositions, together with strategies to secure the manufacture of materials having optimum properties from the economic perspective.

Fundamentals for future information technologies
Information and communications technology is an important sector of the economy, currently employing around 800,000 in Germany. Key technologies for this segment are studied at, amongst others, the Jülich Research Centre where for example work is done on developing alternative oxides for data storage (e.g. hafnium oxide) or the use of iridium as an electrode material in, for example, spin valves.

NANOMICRO: Science, Technology, Systems
The "NANOMICRO" programme ties in with resource technology, primarily in the development of technologies for energy storage. The newly founded Helmholtz Institute Ulm for Electrochemical Energy Storage together with the Karlsruhe Institute of Technology is studying current forms of energy storage, such as lithium ion battery technology, as well as future nano forms. Nanocrystalline metals are also being investigated at the Karlsruhe Institute of Technology, for example with regard to their plasticity. At the forefront here is the analysis of deformation mechanisms and conditions and of alloy compositions, together with strategies to secure the manufacture of materials having optimum properties from the economic perspective.
As the national research institution, the Helmholtz Institute Freiberg for Resource Technology, founded in 2011, has set as its objective the development of new technologies that can provide Germany’s economy with urgently needed mineral and metal-bearing raw materials. The focus is on the development of material- and energy-efficient technologies for the economic utilisation of both primary and secondary raw materials of complex composition, particularly for high-tech metals of strategic economic importance. The aim is to establish interdisciplinary resource technology research encompassing the entire raw material value chain, from exploration and extraction of the raw materials, through processing and refining, to recycling. The priorities of the research, in addition to increasing availability of primary and secondary raw materials whilst retaining long-term material and energy efficiency, are product-specific raw material selection and substitution and the assessment of the sustainability of resource technologies. This holistic approach enables the Institute to meet a strategic need in the German and European industry and research landscape. Both founding partners – the TU Bergakademie Freiberg and the Helmholtz Centre Dresden-Rossendorf (HZDR) – bring their expertise to the Institute. The close location-based cooperation between the Institute and TU Bergakademie Freiberg also offers the opportunity to provide education and training opportunities which in the long term will secure the new generation of scientists for resource-based technology research in Germany.
Fraunhofer Society for Applied Research

With over 80 research institutions worldwide – 60 of them Fraunhofer Institutes in Germany – and over 20,000 employees, the Fraunhofer Society (FhG) is the largest applied research organisation in Europe. In line with the increasing social importance of the topic, resource efficiency is a key issue at virtually every institute. Around 350 scientists and some 115 non-scientific personnel at Fraunhofer were working on research into raw materials of strategic economic importance in 2011. In addition to projects on energy efficiency and the conservation of fossil energy resources, almost half the German institutes were engaged on their own projects or were in collaboration on the issue of how metal resources may be conserved.

The research priorities of the R&D programme for new resource technologies benefit for example from the connectivity of the Fraunhofer Society in themed research groups. Of the six Fraunhofer groups, the Fraunhofer Group for Production and the Fraunhofer Group for Materials and Components – MATERIALS relate directly to this programme. The other four Groups look at specific aspects, for example substitution of materials or new technologies having a different raw material profile.

Of the numerous institutes of the FhG, several major players with high levels of expertise are currently working in the resources field. The list below identifies only the relevant fields of activity from the comprehensive portfolios of these institutes:

- **Fraunhofer Institute for Chemical Technology ICT, Pfinztal (Berghausen)**
  Separation, recycling, lifecycle and waste management

- **Fraunhofer Institute for Laser Technology ILT, Aachen**
  Mineral deposit exploration, raw material characterisation, analysis of secondary raw materials

- **Fraunhofer Institute for Silicate Research ISC, Würzburg**
  Material development, application development

Alongside climate change and healthcare, lack of resources represents another major challenge to society to which appropriate importance will be attached in the Fraunhofer Society’s future direction. A portfolio process cutting across all the institutes has identified five research-intensive, high-growth “Markets beyond tomorrow”. Since 2011 the areas of research relevant to these markets have been further extended. Included is a theme that has for some time been firmly established in the Fraunhofer Society: “Producing in cycles”, which is directly linked to the current R&D programme. The other fields relate to the areas of health, disaster management, electricity and mobility. The last two research areas in particular are also closely interwoven with the theme of resources, for example via the associated need for technology raw materials.
The markets of the future have been allocated to an initial internal selection phase of five “Beyond Tomorrow projects”. In the pilot project “Molecular Sorting for Resource Efficiency”, several Fraunhofer Institutes (IBP, ICT, IGB, IKTS, ISC, WKI) are collaborating in the development of separation processes at the lowest level necessary, in particular for metallic, mineral, biogenic and fossil raw materials. In the “Supergrid” and “Hybrid energy storage system for urban use” pilot projects, material – and thus raw material – aspects also play an important role.

The expansion of the resources theme is also reflected in institutional expansions at the Fraunhofer Society. Under the lead agency of the Fraunhofer Institute for Silicate Research (ISC), a new project group is currently being created: the Fraunhofer Project Group for Materials Recycling and Resource Strategies (IWKS). Their working focus is on resource efficiency, recycling technology, processing technology and material substitution.

The Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT in Oberhausen is reinforcing its competence in the resources area through the incorporation of the ATZ Development Centre at Sulzbach-Rosenberg, which has been conducting research in the fields of energy, raw materials and materials since 1990. The motto “Producing without raw materials”, in other words based on secondary and renewable input materials, will form a focus at both sites. The operational areas of the Fraunhofer UMSICHT-ATZ are energy technology, energy storage systems, new materials (such as raw materials and materials for energy technology), waste management, resources management and recycling (such as metallurgical recyclables recovery extraction processes).

With the two expansion measures, groups of researchers with recognised expertise at the Fraunhofer Society are being integrated and significant synergy effects, both within and cutting across the institutions, will be achieved.

**Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen University)**

At the Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen University), the Faculty of Georesources and Materials Engineering covers research and teaching right through the value chain, from raw to working material. It is the founding component of the university, which due to its proximity to the coal, iron and steel industries in Aachen, Stolberg and Lüttich was established in 1870 as a “Polytechnic College”.

Today, the faculty has approximately 600 members of staff, 3,500 students and around 900 freshers a year and belongs to the largest research centres in the material engineering field worldwide, whether for georesources or recycling. 135 external lecturers strengthen links with industry and bring practical experience to academic teaching. The 43 professors, 370 scientific members of staff and approximately 220 non-scientific personnel are historically organised into the GuG (Geosciences and Geography), FRE (Raw Materials and Disposal) and MuW (Metallurgy and Materials Engineering) departments. Today however, the barriers both with regard to academic courses of study and research projects have been dismantled: cross-cutting themes are handled jointly, drawing upon external skills. Via integrated programmes and forums, materials bridge mechanical engineering, civil engineering and electrical technology, led by additional professorships for specialist materials science. The large-scale cross-faculty projects in the field of resource security include SFB525 material flows and the Rare Earth – Green Mining and Separation research division set up in Aachen by Siemens in 2011. This sees for example cooperation between the Institutes of Mineral Deposits, Mining, Processing and Metallurgy in four-year programmes. Externally this is conducted by the non-profit-making Aachen Competence Centre for Resource Technology (AKR) supported by over 20 professorships, integrating additional know-how from the fields of raw materials law and extractive industries.

The general strength of Aachen lies in the applied research at all levels of the value chain, extending into processing and metallurgy from experimental research up to demonstration scale. The basic and analytical expertise of the Faculty of Natural Sciences was successfully integrated in order to develop methods...
and be able to describe their mechanisms. This cooperation is demonstrated in the strategically desirable rapidly-growing number of publications in internationally acknowledged and reviewed journals and conference proceedings. The following summarises the contributions of the three departments in Aachen’s resources expertise.

At the forefront is process research focused on raw material, such as the origins of deposits of metallic and non-metallic ores and fossil fuels (crude oil, natural gas, shale and seam gas, and coal). An important role is also played by the development of genetic models and exploration concepts, together with the techno-economic and ecological evaluation of the use and risk potential of the raw materials. Integrated raw material research by the EMR Group is based on the concept of “ore system analysis”, an approach examining and integrating all the geological parameters that control the formation and production of energy and ore resources.

The Raw Materials and Disposal Technology Department has nine professorships covering the areas of raw material extraction and raw material process technology. Building on many years of research and development work, the following themes relating to the securing of resources have emerged:

• large-scale selective raw material extraction by knowledge-based machine optimisation/control and on-line quality monitoring of the raw materials extracted

• variable use of polymetallic deposits by modelling of the time and quality extraction sequence with operational assessment

• assessment of sustainability aspects and acceptability issues in raw material extraction

• research on the extraction-based use of unconventional deposits

• tapping into secondary resources from waste by optimising the process chain to enhance values

Work in the field of raw material extraction is therefore steadily being concentrated on increasing efficiency in the utilisation of mineral deposits, on the selection of parts of deposits determined by need and quality, and on exploiting previously unused resources. The raw material technology focus looks at ways to optimise the throughput of valuable constituents of primary and secondary raw materials and to assess the efficiency of enrichment processes. Following the process chain, the focus encompasses topics such as:

• adaptation of mechanical processes for concentrating the value in raw materials
metal production and degree of purity, research goals are the synthesis of alloys from increasingly poorer and more complex precursors (ores and secondary materials). From the point of view of sustainability, energy management is of particular importance. Selected themes in both current and future work are heat recovery extraction from gas and slag, use of the reduction potential of waste gases, use of biomass and hydrogen, and the integrated recycling of plastics in metallurgical processes.

Technical University Bergakademie Freiberg

The Technical University Bergakademie Freiberg brands itself as “The University of Resources. Since 1765”, the centre of mining sciences in the Saxony city of Freiberg. The strategic development of the University of Resources is geared towards fine-tuning the resources profile particularly with respect to sustainability, making the resources profile more attractive to society, and to the integrated value chain via innovation through to trialling under technically-near-equivalent conditions. The proven tradition of sustainability can be traced back to the shaping of the term sustainability by Freiberg’s mining administrator Hans Carl von Carlowitz (1713).

The resources profile is the scientific profile of the sustainable material and energy management along the value chain of the raw materials. This includes the process chain for the processing of natural raw materials from exploration through extraction, refining / processing into the processed product, and recycling. The scientific disciplines of mathematics and computer science, natural sciences, the engineering sciences and economic sciences are linked over the whole of the value chain in both research and in education (with over 30 courses of study). Around half the total 88 professorships have their scientific focus in one of the value adding stages or in the four profile lines geosciences, material sciences, energy and environment.

In terms of raw materials engineering, the department deals with residues and material lifecycles in metallurgy (dust, slag, CO₂ emissions, refractory materials), and also with upstream and downstream process stages (spoil, scale, dust, chips, scrap etc.). Also included are end-of-life products such as scrap cars, electronics, batteries, catalysts and even solar collectors. Methods used for their processing through to a marketable product (metal / alloy / compound) encompass electrometallurgy, vacuum metallurgy, injection technology, agglomeration and hydrometallurgy / applied electrochemistry and supporting process modelling. These methods are of particular interest at RWTH Aachen University. In addition to the German Research Landscape for Resource Technologies
not only highly qualified scientists, but also experts in the securing of raw materials supply to industry. As the oldest mining university in the world it fulfils its responsibility, that of anchoring its governing principle of sustainable development in the raw materials sector, in the training of expert and management staff worldwide. With this in mind, together with the St Petersburg State University, the second oldest mining university (since 1773, based on the Freiberg model), it founded the World Forum of Universities of Resources on Sustainability.

The Freiberg resources profile is attracting increasing interest both nationally and internationally; student numbers have trebled in the last 15 years. Of the current some 5,700 students (2012 figure), 80% are studying “STEM” subjects and around 60% engineering sciences. In geotechnology and mining, most students do not come from Saxony. Around 20% of students in the first semester come from the raw material countries of Eastern Europe, Asia and South America. In the narrower field of mineral and non-energy raw materials there are some 1050 students, approximately 320 of them freshers. In teaching and research on non-energy mineral raw materials there are 24 professors, 224 scientific members of staff and 98 non-scientific personnel.

In 2001, the Freiberg Geocompetence Centre, the largest mining network in Germany, was founded with geopartners from Saxony. Working in the Centre as well as the TU Bergakademie Freiberg we find over 120 geoscience companies, the Saxony Mining Authority, the Saxony Mining Archives, and the Geology Service (State Office for the Environment, Agriculture and Geology).

Continuing the traditionally close ties with Russia, Eastern Europe and Central Asia, the university has developed into the key university for these regions in the field of mineral raw materials and fuels, and is a partner in the International University of Resources (IUR) association along with four European mining universities - Dnepropetrovsk (Ukraine), Krakow (Poland), Leoben (Austria) and St Petersburg (Russia). The first joint Masters course in mining engineering began in 2012. Together with the mining university of St Petersburg, the Bergakademie Freiberg has since 2006 been cooperating in the German-Russian Raw Materials Forum, the most important non-governmental platform in raw materials cooperation with Russia. The Federal Government’s raw materials partnerships with Mongolia and Kazakhstan have been and are being prepared and monitored at scientific and university level.

Freiberg has access to an eminent gearchive for mining work, in particular the national library collections of the German Research Foundation (DFG), geoscientific resources and collections of mineral raw materials and coal, an historic model collection, an impressive geodata collection and the collections of the Saxony Mining Archive.

Characteristic of research at the University of Resources is the cross-cutting nature of the value adding stages, achieved via interlinked innovation chains spanning from theory through to near-industrial-scale trials. A science-innovation chain unique in Germany in this context extends from mineralogy, crystal physics and chemistry through to materials science and engineering. Examples of raw material-based innovation chains are the Lithium Initiative (from the exploration and extraction of lithium through to battery storage material and recycling), the Magnesium Competence Centre (from raw material to magnesium construction material), the High-Pressure Centre (from molecule through to superhard material) or the Centre for Energy Raw Material Research DBI | Mining Academy (looking at fossil fuels, from exploration through to the chemical raw material). A unique selling point of the university is that it has its own teaching and research mine, the Reiche Zeche. Other near-industrial scale research facilities there include research rolling mills, near-industrial-scale energy conversion and chemical pilot plants, foundry research facilities or semi-industrial smelters, or a large-scale shear device. The university plans to further expand the large-scale research facilities (for example the Smart mining research mine and carbon institute).

In raw material and material research, the DFG has two collaborative research centres (TRIP-Matrix-Composites, multifunctional filters for molten metal filtration), two priority programmes (Refractories – Initiative to Reduce Emissions, algorithms for rapid material-appropriate process chain structure and analysis in plastic deformation), a Land excellence programme (Atomic Design and Defect Engineering), the Freiberg High-Pressure Research Centre, a project for validating innovation potential (self-glazing carbon-bonded functional components for steel metallurgy and casting with self-healing properties),
three Innovative Regional Growth Cores (Hybrid Lithium Extraction, Innovative Lignite Integration, Magnesium Growth Core) and two Federal Centres of Excellence (virtualisation of high-temperature conversion processes, German Centre for Energy Resources).

Teaching and research mine “Reiche Zeche”

The TU Bergakademie Freiberg is the only university in Germany, and indeed in Europe, with its own mining operation used for research and for specialist training of students and junior management. Use of a working research mine at a university in this way is in fact unique in the world. In the field of research, great efficiencies can be obtained in the areas of exploration, extraction and trialling of equipment, as well as the testing of new processes. The research infrastructure as of now actually encompasses geophysical and geotechnical trial and test benches and an explosion chamber for material synthesis unique in Europe. Ongoing conversion works on the Reiche Zeche shaft and plans to drive a new access fit for traffic, with the unique conditions for research and experimental studies directly in situ, improve the prospects for use. Students on geoscientific and geotechnical courses will for example leave the research mine with practical experience in the fields of mining technology, explosives, mine ventilation, tunnelling, rock mechanics, surveying technology, geophysics, geothermy and environmental geochemistry.
The German Research Landscape for Resource Technologies

Technical University Clausthal

Research into resource technologies forms a classical and traditional area of research in the Clausthal region, conducted by the TU Clausthal as successor to the former mining academy in association with research institutions such as the Clausthal Environmental Sciences Institute (CUTEC) and partner institutes within the Association of Lower Saxony Technical Universities (NTH) (TU Clausthal, TU Braunschweig, Leibniz University Hanover).

There are currently eight institutes with 18 professors working in the core area of resource technologies, plus 132 scientific and 58 non-scientific staff members. A total of some 750 students are enrolled in the Energy and Raw Materials Section, with around 150 freshers annually. In resource technologies TU Clausthal works very closely with companies in the extractive industry. A number of companies are headquartered in this region as a result of the mining tradition in the Harz area, and as world market leaders contribute significantly to the competitiveness of the Federal Republic of Germany. The collaborative chain extends right through to product manufacturers, such as the automotive industry, which are heavily reliant on a secure supply of raw materials.

Resource technologies research at the TU Clausthal is shaped by institutes covering geosciences, mining, crude oil and natural gas technology, processing, metallurgy, materials sciences and materials engineering. The institutional structure of the TU Clausthal allows it to offer the possibility of covering every aspect of the extraction and processing spectrum for primary and secondary raw materials.

More than 15 institutes across all three faculties work here and cooperate closely. These collaborations within the TU Clausthal have generated research centres such as the Clausthal Centre for Materials Engineering, in which various institutes along the raw material-to-material chain work together. The collaborations extend beyond the boundaries of the TU Clausthal itself, and are increasingly being set-up with partner universities in the NTH association.

The TU Clausthal additionally maintains a close research partnership with CUTEC, a research institute based in Lower Saxony with around 100 staff members that has established a strong expertise in resource efficiency.
At the TU Clausthal the investigation, exploration and analysis of raw economic geology form the themes for the research work at the Institutes of Geology and Geophysics, and for the Chairs of Mineralogy and Mineral Deposits at the Institute of Disposal Research. The extraction of mineral and energy raw materials falls under the remit of the Institutes of Mining and Petroleum and Natural Gas Engineering. These institutes concern themselves with the exploitation of deposits found in quarrying and tunnelling, deposit technology and deposit simulation, together with the extraction of raw materials. Priorities in recent years include optimising the planning of raw material operations, efficient raw material extraction, deep geothermal energy and deep seabed mining.

The Chair of Raw material processing and Recycling at the Institute of Mineral and Waste Processing, Waste Disposal and Geomechanics traditionally looks at the processing of primary raw materials with the focus on ores and industrial minerals. In recent decades, research focused on the areas of efficient impact crushing, flotation and leaching. Based on the development of technologies in the processing of primary raw materials, the 1970s saw the beginning of the development of recycling technologies. Residues from production, such as from raw material extraction, the iron and steel industry and the manufacture of complex products such as the automotive industry, have since provided a focus for the work. The development of recycling technologies for end-of-life products and equipment such as scrap vehicles, electronic scrap and batteries have taken on increasingly greater importance in recent years. Recycling technologies are being developed in parallel with the development of new products, such as we see in the electric mobility sector.

The Institutes of Metallurgy, Non-Metallic Materials, and Polymer Materials and Plastics Engineering are active in the area from raw material to precursor. This also includes the transition from precursor to material, with priorities for example being the development of complex new materials and materials from secondary raw materials (recyclates). There is particular emphasis on research expertise in light metals, light metal alloys and fibre composites, ceramics, glass and cements.

Various institutes working in the areas of material and material processing technologies are researching and developing the next steps towards application-specific and available materials, semi-finished parts and components.

The institutional research activities mentioned are accompanied by work by the Institutes of Economics and of Environmental Science, which addresses the economic appraisal and steady development of new environmentally friendly measures throughout the process of energy and raw material extraction. The same is true of the work of the Institute of German and International Mining and Energy Law whose research work covers the legal framework of a wide variety of projects in energy and raw material extraction.

Significant developments are currently underway in the Clausthal/Goslar region in the recycling of metals of strategic economic importance. In addition to their previous three research centres, the TU Clausthal has set up the Recycling Cluster. In line with this, CUTEC is further developing their Sustainability Management Cluster. In October 2011 the TU Clausthal and CUTEC, together with eight leading regional enterprises from the raw material/precursor and recycling sectors (including H. C. Starck, PPM and Electrolyzing) plus the Goslar Administrative District, the Goslar Economic Region and the GMB, set up the Lower Saxony Economically Strategic Metals Recycling Cluster (REWIMET).
2.2 Current research funding by the BMBF

Research funding on raw materials and resource efficiency by the BMBF is closely intermeshed with funding activities by other departments, in particular the BMU and the BMWi (see Table 1).

BMBF support programmes

The BMBF runs several specialised programmes supporting research and development projects on the topic of resource technologies. The following in particular are of relevance here:

- **FONA – Forschung für Nachhaltige Entwicklungen** (Research for Sustainable Development)
- **WING – Werkstoffinnovationen für Industrie und Gesellschaft** (Materials Innovations for Industry and Society)
- "Research for the Production of Tomorrow” programme

Other BMBF programmes support R&D projects that also have links to certain aspects of resource technologies and raw materials of strategic economic importance, for example in programmes for new technologies (ICT 2020, Energy Research Programme) or for regional R&D support (Entrepreneurial Regions).

FONA – Forschung für Nachhaltige Entwicklungen (Research for Sustainable Development)

Within the “Research for Sustainable Development – FONA” framework programme of the ‘Sustainable Economies and Resources’ action plan are established several support measures relevant to the “Raw materials of strategic economic importance for high-tech made in Germany” R&D programme.

- **r² – Innovative Technologies for Resource Efficiency – Resource-Intensive Production Processes**

  The focus of r² is on resource-dependent industries with high use of raw materials, because great leverage can be achieved here to increase raw material productivity, for example in the metal and steel industry or in the chemical, ceramic and construction materials industries. In the period 2009 to 2013 a total of 22 collaborative R&D projects are being supported by enterprises in the business sector together with research institutions, with total funding of approximately EUR 38 million plus a further EUR 18 million provided by the enterprises involved.

Table 1: Selected Federal Government raw material-based funding activities

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<thead>
<tr>
<th>Stage in the support cycle</th>
<th>BMBF</th>
<th>BMU</th>
<th>BMWi</th>
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<tr>
<td>Technology development, R&amp;D</td>
<td>r² and r³, CLIENT SME Innovative, MatRessource etc.</td>
<td>Masterplan for Maritime Technologies (marine raw materials)</td>
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<tr>
<td>Demonstration phase</td>
<td>Environmental Innovation Programme</td>
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<td>Market launch and implementation</td>
<td>Resource Efficiency Network</td>
<td>VDI Centre for Resource Efficiency</td>
<td>demea innovation vouchers – raw material and material efficiency module</td>
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<td>Strategic activities</td>
<td>Interministerial Raw Materials Committee</td>
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<td>R&amp;D programme for new raw material technologies, HIF</td>
<td>ProgRess</td>
<td>BGR / DERA raw material partnerships</td>
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resource and energy efficiency. In the area of resource efficiency, more than 130 projects with total funding of approximately EUR 25 million have been supported since 2007. The successful funding measures should continue, with six-monthly submission deadlines for project ideas (up to EUR 6 million per year).

- **International Partnerships for Sustainable Technologies and Services for Climate Protection and the Environment (CLIENT)**
  The focus of CLIENT is on the research and development of adapted sustainable technologies and services together with partners from Brazil, Russia, India, China, South Africa and Vietnam. Using prototypes or pilot applications, these will be implemented in the areas of climate change, resource use, land management and water management. In total, collaborative projects will receive funding totalling EUR 60 million in the period 2010 to 2016; of this, it is anticipated that approximately one quarter will be allocated to resource use.

- **KMU-innovativ (SME Innovative): Resources and energy efficiency**
  With the ongoing SME Innovative funding initiative, the BMBF is pursuing the goal of consolidating the innovation potential of small and medium-sized enterprises (SMEs) in the area of cutting-edge research and making research funding more attractive as part of its specialised programmes, particularly for first-time applicant SMEs. In the technology field of resource and energy efficiency SMEs receive support to develop innovative technologies and services for improved resource and energy efficiency. In the area of resource efficiency, more than 130 projects with total funding of approximately EUR 25 million have been supported since 2007. The successful funding measures should continue, with six-monthly submission deadlines for project ideas (up to EUR 6 million per year).

- **r³ – Innovative Technologies for Resource Efficiency – Strategic Metals and Minerals**
  As part of r³, collaborative projects between industry and science are supported with the aim of achieving advances in efficiency in resources utilisation. The focus is on increasing raw material efficiency, recycling and the substitution of scarce raw materials of strategic economic importance. A further theme focus is on “urban mining” to recover strategic raw materials from anthropological deposits, for example from old landfills. Funds totalling EUR 30 million and significant additional contributions from enterprises are anticipated for research associations, which started in mid-2012.

Figure 11: Wash residues from copper extraction at Tierra Amarilla, Chile (source: Maike Hauschild, PtJ).
WING – Werkstoffinnovationen für Industrie und Gesellschaft (Materials Innovations for Industry and Society)

The “WING (Material Innovations for Industry and Society)” framework programme also promotes R&D projects for material development in small and medium-sized enterprises as part of SME Innovative.

The following funding measures are also relevant for the topic of resource technologies:

• Materials for a resource-efficient industry and society – MatRessource
  The aim of the BMBF’s MatRessource funding initiative is to provide effective impetus to increasing resource efficiency through material innovations. The following themes form the focus of the funding:
  • Substitution and efficiency of materials: recycling of nanomaterials; reduction of the reliance on strategic metals and increasing specific material yields; development of nanomaterial recycling
  • Corrosion protection: improved surface protection systems and new materials with considerably greater corrosion resistance to increase the life of components and systems and to increase the efficiency of energy systems
  • Catalysis and process optimisation: security of supply of raw materials by (new) catalysts adapted to changes in the raw material basis of the extractive industry; saving of resources by increasing catalyst service life; process intensification by more active catalysts and multifunctional reactors with simultaneous increasing of energy efficiency

Approximately EUR 30 million of funding for R&D projects was made available in the first selection process in 2011; there was a further selection process in 2012.

• Multi-material systems – future lightweight construction for resource-efficient mobility
  The BMBF’s multi-material systems funding measure is aimed at the development of holistic lightweight construction approaches for vehicles which make it possible, by using multi-material systems, to reduce the weight of the vehicle and make energy savings and at the same time realise increased demands for e.g. passenger comfort and safety in the vehicle. Achievement of this will require the use of customised combinations of materials and upgrading of the joining technologies needed. Consequently, the potential of multi-material systems with regard to savings in terms of weight, costs and resources for conventional and future vehicle concepts (cars, aircraft and rail vehicles) should be exploited.

• Key technologies for electric mobility (STROM)
  As part of the “Key Technologies for Electric Mobility (STROM)” announcement in the WING and “ICT 2020 – Research for Innovation” framework programmes, the BMBF supports the development of resource-conserving technologies for electric vehicles. This includes for example recycling solutions for electric motors from electric and hybrid vehicles in order to recover rare earth metals from permanent magnets.

• LIB 2015 Lithium Ion Battery Innovation Alliance
  In the Lithium Ion Battery LIB 2015 Innovation Alliance set up in 2007, an industry consortium of BASF, BOSCH, EVONIK, LiTec and VW committed to invest EUR 360 million over the next few years for research on and development of the lithium ion battery. This is supplemented and complemented by EUR 60 million of funds from the BMBF for this sector. In addition to the development of new materials for lithium ion accumulators, a low-waste, innovative recycling process for the economic recovery of the materials from lithium ion-based vehicle batteries is being studied.
Research for the Production of Tomorrow

A priority of the “Research for the Production of Tomorrow” framework programme is to increase resource efficiency in production. The focus here is on the funding of R&D projects on the following topics:

• energy-efficient processes and technologies in production and processing engineering
• energy-efficient production equipment
• targeted setting of product properties by production technologies taking into account resource efficiency in product and process
• components with resource-efficient, locally functional surfaces

As many different target groups as possible, in particular production companies, should benefit from the results of the research. A joint innovation platform, Resource-Efficient Production – Efficiency Factory for short – was accordingly set up as a joint venture between the BMBF and the German Machinery and Plant Manufacturers Association (VDMA). The results of this R&D project can be seen at www.effizienzfabrik.de.

• Innovation Alliance Green Carbody Technologies

The Innovation Alliance Green Carbody Technologies – a nationwide network of 60 enterprises in the automotive industry (OEMs, suppliers, equipment suppliers) and the production Fraunhofer Institutes at Chemnitz (IWU), Aachen (IPT) and Stuttgart (IPA) – undertakes research on issues of energy and resource efficiency in the manufacture of vehicle bodywork. The opportunities and aims here lie both in the aspect of energy and resources savings for climate protection, and the potential for sustainable German production innovations on the world market. A period of three years (starting on 1 January 2010) is planned for projects in the Innovation Alliance. The research volume of the enterprises involved totals approximately EUR 100 million, of which EUR 30 million is invested in joint collaborative projects. The BMBF supports this innovation alliance of EUR 15 million.

• Energy-efficient lightweight construction

As part of the “Energy-Efficient Lightweight Construction” funding notice, the BMBF is funding R&D projects on the development of new resource-conserving manufacturing and processing technologies, and the required production equipment, for the economical and resource-efficient manufacture of lightweight construction products built of fibre composites and multi-material systems.

• KMU-innovativ (SME Innovative): production research

In addition, as part of SME Innovative in production research, R&D projects are being funded in small and medium-sized companies including a particular focus on more energy-efficient production machinery and plant together with their components.

Entrepreneurial Regions - innovation initiative for the New German Länder

As part of the BMBF’s Entrepreneurial Regions innovation initiative, the “Hybrid Lithium Extraction” collaborative project has since March 2011 received support at the Bergakademie Freiberg. The goal is the better use in Germany of existing raw materials potential. The planned surveying and characterisation of the known deposits (zinnwaldite, deep waters containing lithium) is the first step towards the exploitation of this and the basis for process development. The same is true of secondary raw material (lithium batteries). A technically and operationally-supported solution for an efficient logistics system and functioning incentive system for increasing the take-back quota should be found and tested under real world conditions. Development of the mechanical, metallurgical and chemical processes should form the basis of a technology platform making it possible to efficiently extract lithium carbonate from a range of starting materials (primary and secondary raw materials).

The building up of regional competences for the supply of raw materials is supported by the BMBF with the funding of the “Lifecycle strategies and recycling of rare metals with strategic importance” and “Probes for hydrogeology and raw material exploration” innovation forums.
3 European and international research on resource technologies

In looking at international research activities, distinction must be drawn between supply side activities and those on the demand side. On the demand side, there are in every industrialised country, and in some emerging countries, comprehensive measures aimed at the substitution and efficient use of materials. Going into these research activities would exceed the scope of this overview.

The situation is different on the supply side however. Here, research activities are concentrated in a few countries rich in resources in which there is greater emphasis on mining and the first stages of the value chain. These include in particular Australia, Canada, South Africa, Brazil, Chile and with a few exceptions the USA. In Europe, Sweden is increasingly taking a prominent position, followed by Austria. The efforts that have been made in the past few years, particularly in Japan, in the field of supply-side resource technology research are interesting.

Figure 12: States outside Germany with leading international research institutions in the field of supply-side resource technology research, covering the whole of the value chain.
3.1 The European research landscape

A leading European research institution in the field of resource technologies is the Luleå University of Technology in Strömsund (Sweden) where both basic and applied research and teaching, with the emphasis on mining technology and metallurgy, is conducted in close collaboration with industry. The value chain of metallic raw materials through to product development is studied, with traditional mining expertise being supplemented by expertise in for example chemistry, statistics and economics.

Also in Europe is the Leoben Mining University (Austria), with a number of Chairs at all stages of the raw material value chain. Research and teaching focus on the supply side on mineral raw materials and sustainable production and technology. On the demand side, the priority is on high-performance materials. The Raw Materials Innovation Centre which with technical, laboratory and experimental areas tackles the framework of requirements for bringing together university and non-university research and development, was completed in 2010. The new Centre, which also develops training facilities for business, is an extension of the Raw Materials Innovation Centre already on the site (demand side).

Eastern Europe has considerable expertise in resource technology research on primary raw materials. Mention should be made of the Krakow Mining and Metallurgy Academy and the specialist universities of mining and metallurgy in Dnepropetrovsk (Ukraine), St Petersburg and Moscow (Russia) which collaborate with specialist scientific research institutes and institutes at the academies of sciences. Special emphasis should be given to the St Petersburg Mining University which has the status of a national research university and is Russia’s flagship university for resource issues. It is home to the centre for the Russian raw materials strategy, with particular competences in mineral deposit exploration and assessment, raw material extraction, treatment and recycling.

The university has worldwide links with industrial enterprises, research institutions and universities.

3.2 The research landscape outside Europe

The international leader in raw material research is the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia. This is the national research authority, and with 15 fields of research and around 5,000 employees at over 50 sites is one of the world’s largest relevant research institutions. As part of the “Mining and Minerals” core research priority, in addition to hydrocarbons CSIRO covers all stages of the value chain of metallic raw materials and their technologies. The initial value-adding stages occupy a prominent place here: the “Earth Science and Resource Engineering” research field concentrates for example on new concepts and technologies for reducing risk in exploration and production. Today, the CSIRO leads the market in exploration technologies worldwide. Overall, raw materials are extremely important to industry and thus to the gross domestic product of the Australian raw material suppliers. Accordingly, the Light Metals Flagship and Minerals Down Under Flagship, both focussed on cost-reducing and efficiency-raising technologies, are two of the ten most important areas in the national flagship research programme. This programme involves science and business working together on an interdisciplinary basis.

In addition to research under near-industrial conditions, supplementary training and educational opportunities are offered at the Sustainable Minerals Institute (SMI) of the University of Queensland in Brisbane (Australia). The research centres at the Institute cover large parts of the metallic raw materials value chain, but not at present recycling. The W. H. Bryan Mining and Geology Research Centre (BRC) runs basic research on exploration, extraction and treatment; the Julius Kruttschnitt Mineral Research Centre (JKMRC) concentrates on developing technology for treatment and refining; other centres study aspects of safety, health and social responsibility in mining and old mine workings, and reclamation.
MINTEK, South Africa’s national raw material research organisation based in Randburg, is also geared towards the needs of the local mineral and metal industry. With some 800 employees, MINTEK is one of the world’s leading research institutions for metallic raw materials and technologies at the treatment and refining stages. The total of nine technology departments include Biotechnology (with the focus on bioleaching), Mineralogy (the focus on exploration), Advanced Materials, and Analytical and Engineering Services. As well as research and development, MINTEK offers a wide range of advisory, testing and marketing services both nationally and internationally.

In Canada the Department of National Resources (National Resources Canada – NRCan) is the national authority and addresses questions of metallic raw materials and their technologies at individual stages of the value chain. In its Minerals and Metals Sector, the research-based CANMET Materials Technology Laboratory (CANMET-MTL) and CANMET Mining and Mineral Sciences Laboratories (CANMET-MMSL) have close links with policy and legislation. Whilst CANMET-MMSL focuses on extraction and treatment and has built up a global reputation for associated technologies, CANMET-MTL concentrates on the refining and recycling of metallic raw materials. Specialising in value-added structural metals, it is one of the leading research centres in this field. A common feature of both institutions is the close alignment of research and development with the needs of the domestic metal-processing industry.

An eminent research institution in the higher education establishments sector in the USA is the Colorado School of Mines in Golden which conducts research primarily in the areas of exploration, extraction and recycling of metallic raw materials. Here again, applied research and the specific training and education offered are weighted towards the current needs of the national industry and organised as interdisciplinary centres.

As regards development both today and in future, and challenges in the raw materials industry, at the end of 2009 for example the Newmont Mining Corporation founded and financed the multidisciplinary Centre for Innovation in Earth Resources Science & Engineering (CIERSE).

In Japan, too, eminent institutions are conducting research on resource technologies. The goal of Japan Oil, Gas and Metals National Corporation (JOGMEC) is to guarantee the stable supply of natural raw materials to Japan. Activities include maintaining an information centre for mineral raw materials, holding and storing rare metals, supporting Japanese enterprises in procuring risk capital for exploration and extraction projects, and the development of new technologies right through the raw material value chain. A further research institute in resource technology has existed since 2009 at the International Centre for Research and Education on Mineral and Energy Resources (ICREMER) at Akita University.

China is currently the major supplier of rare earths worldwide and at the same time one of the largest consumers of raw materials. Well-known research institutions include the Guangzhou Research Institute of Non-Ferrous Metals (GZRINM), the General Research Institute for Non-Ferrous Metals (GRINM) and the National Science Promotion Centre (NSPC). The GZRINM studies all areas of the raw material value chain with both basic and applied orientations, focussing on technologies, and with over 1,200 employees working in research has a high scientific capability. The GRINM, with over 2,000 researchers, works predominantly on the treatment and refining stages of the value chain with the focus again being on technology. The NSPC is headquartered in the Baotou National Rare-Earth Hi-Tech Industrial Development Zone and with around 70% of Chinese production is the most important site in China for the production of rare earths.

In South America, the Centro de Tecnologia-Mineral (CETEM) in Brazil and the Centro de Investigación Minero y Metalúrgico (CIMM) in Chile work in resource technology research.
4 Future research and development needs

Research and development activities in Germany to date have been weighted toward the raw material demand side, for example to reduce material input through innovative products and processes. The work on the demand side should be continued; there is in particular further need for substitution of raw materials of strategic economic importance through new material and technology developments. The rapidly climbing demand for these raw materials in the emerging technology areas of the future (for example, renewable energy technologies) should then as a result decline.

Analysis of the current research landscape in Germany shows that on the raw material supply side in particular, research and development activities need to be reinforced, and it is here that the BMBF’s Resource Technologies Advisory Committee sees significant need for research and development to increase domestic supply of raw materials of strategic economic importance. This concerns both the efficient and environmentally responsible provision of primary raw materials, and recycling to yield secondary raw materials. Industry in Germany supports this view. The needs for research and development are discussed in detail in the following.

4.1 Primary raw materials and exploration

Research along the value chain

Germany has assumed a global leadership role in the processing of secondary raw materials, which is set to continue to expand. Nevertheless, as one of the world’s market leaders in key and high technologies, the German national economy will remain heavily dependent upon primary raw materials in the future. As demand for raw materials in the emerging countries is also rising, competition on the global raw materials market is becoming keener. Worldwide demand cannot currently be met solely by closed material cycles. Particularly for the so-called electronic metals, such as gallium, germanium and indium, recycling alone is insufficient to provide the quantities required by German industry. Here again, extraction by mining is required in the long term.

In Germany, comprehensive research expertise for the whole primary raw materials value chain is concentrated at the RWTH Aachen University, the Technical University of Clausthal and the Technical University Bergakademie Freiberg. Mention should also be made of the Federal Institute for Geosciences and Natural Resources in Hanover (see Chapter 2). Specialist know-how on individual value adding stages also exists at other locations. If primary raw materials supply to the German national economy is to be secured in the long term, these areas of expertise must be consolidated, expanded and effectively integrated.

The following will look at the priority for research for each of the major steps in the primary raw material value chain, from exploration through mining to processing and metallurgy. It will also consider those research fields that span the entire value chain in the extractive industries and the analysis of resources, together with ecological, social and political aspects of the global extractive industries.

Exploration

In the exploration sector, new processes must be developed allowing deeply buried deposits of raw materials to be identified. Whether remote sensing, geophysical, geochemical or mineralogical exploration processes, all should have the objective of minimising their physical impact on the environment. This is also important in order to improve the social acceptability of raw material exploration and extraction. Exploration processes that will allow new deposits of raw materials of strategic economic importance to be identified also need to be developed, including both deposit-genetic aspects and the derivation of proximity indicators.
FUTURE RESEARCH AND DEVELOPMENT NEEDS

Mining

The extraction of primary raw materials by mining must become more energy- and material-efficient; there is a pressing need for research on this. A number of areas can be targeted for increased efficiency. Existing operational processes should be optimised and automated, or new technologies in rock-cutting developed, for example through mechanical means underpinned by high-pressure water jets and micro-waves. Transporting material and other mining processes can also be further optimised. Additional potential lies in the use of networked information systems and sensor/actuator technology and robotics for integrated production planning and control. Planning on this basis can contribute to better integration of the extraction process with upstream geological characterisation and downstream treatment processes. Other fields of research are highly-selective extraction, and the minimisation of material transport by treatment and backfilling taking place close to extraction. This can result in improvements in both efficiency and safety in mining. Automation of the extraction process means fewer people needed to be actively engaged in mining, which consequently reduces the specific risks, particularly in respect of deep mining (keywords "smart mining" or "green mining"). As opencast operations are becoming ever deeper, new technologies are required; this should mean safer and more environmentally-responsible quarrying and mining.

New processes are of particular importance for the exploration of domestic raw materials potential, which also includes reassessment of known deposits. The models employed to date in Germany for mineral raw materials deposits are not however adequate for international comparison, meaning that exploration-relevant 4D metallo-genetic models need to be developed as part of the reassessment in order to address uncertainties in known deposit areas in Germany. Known records need to be reinterpreted and new, up-to-date mineralogical, geochemical and in particular geochronological data provided. Using these data, the genesis of the deposits can be interpreted and exploration concepts for identifying hitherto unknown raw material deposits derived. This applies above all to the potential for high-tech metals of strategic economic importance that up to now have not been part of mining activities in Germany.

In this context, efforts should be made to find new high-resolution aero-geophysical data nationwide or at least in those regions having particular raw material potential. Ireland and Northern Ireland are good examples here: their successful Tellus Initiative provided positive impetus for the exploration of domestic raw materials.
FUTURE RESEARCH AND DEVELOPMENT NEEDS

**Treatment**

Material and energy efficiency must also be increased in treatment processes, with particular emphasis on optimising energy-intensive crushing processes in order to obtain improved release of all the components of value contained in the raw material with lower use of energy and material. The use of sensor-based sorting processes pursues this goal. While these processes are in fact occasionally employed in the raw materials industry, they have the potential for further development. Technologies for efficient separation – particularly flotation – even for complex and fine-grained polymetallic raw materials make possible the utilisation of virtually all value components contained. These technologies can also however be further developed. This requires new concepts in operational management that no longer focus exclusively on a single main component such as copper or gold, but aims to use the raw material obtained as comprehensively as possible without leaving any residues. Concepts such as this are currently implemented internationally in only very few mining and foundry operations, for example the Palabora Mining Company in South Africa.

**Metallurgy**

In the metallurgical processing of treatment products, the primary focus should be on studying options for increasing material and energy efficiency. Whilst pyrometallurgical processing is in some cases very energy-intensive, hydrometallurgical processes often involve large quantities of waste water. In many processes, a large part of the value components are converted to intermediates such as slurry, slag or fine dust, or is lost in the waste slag which must then be retreated by internal recycling. For the well-developed industrial processes for iron, copper, zinc or aluminium – i.e. widely-used metals, there is little need for research around the major metal. Nonetheless, due to the quantities involved enormous potential remains for efficiency improvements here. New technologies must be developed in particular for utilisation of the less concentrated accompanying raw materials. These rare metals usually occur as associated components in the major metals above, which is why their extraction requires additional involvement and hence developments in this area also. Accompanying raw materials also include a number of metals of strategic economic importance such as indium, gallium, germanium and molybdenum. Research is urgently required here to develop energy- and material-efficient technologies for using accompanying metals of this type and verifying the often unknown raw material potential (for example gallium and indium in bauxite, germanium and indium in zinc ores).
Chemical and in particular microbiological leaching processes are another important field of research for the primary raw materials sector. These processes enable metals at low initial concentrations to be efficiently extracted with relatively low energy input and at low temperatures, frequently resulting in a better environmental balance in comparison with other processes. Microbiological leaching processes in particular are very energy-efficient. Rapid development of these processes for the use of complex polymetallic raw materials appears feasible in principle, but requires considerable research efforts.

The use of biosorption holds considerable potential in the concentration and separation of metals, particularly metals of strategic economic importance. In biosorption, cell proteins are applied to corresponding substrates in order to precipitate metals with high selectivity from highly diluted metal-containing solutions. These metals can then be removed from their substrate film and chemically precipitated. The combination here of microbiological leaching with subsequent biosorption appears to promise particular success for efficient raw material extraction. Biosorption processes have not to date been used industrially, but there remains substantial need for research here.

Marine raw materials

The scientific exploration of polymetallic manganese crusts and nodules, as well as polymetallic sulphide deposits, has made significant progress in the field of marine raw materials. Corresponding raw material potentials have already been demonstrated and initial concepts for economic geological assessment and mining extraction are being drafted. What is lacking however are technologies able to extract these raw materials sustainably and with material and energy efficiency. Technologies for treatment and metallurgy are also required, particularly for the use of polymetallic manganese crusts and nodules as a source of strategic metals. The effects of raw materials extraction on the affected ecosystems must also be examined in the context of technology assessment. Germany is currently actively pursuing the exploration and use of marine raw materials; the topic of marine mineral raw materials is already being addressed in the BMWi’s National Masterplan for Maritime Technologies and is not part of the present programme.

Approaches to evaluation

The exploration, extraction and utilization of primary raw materials – including the application of innovative technologies – should always be accompanied by sound ecological, economic and social assessment and sustainability indicators that are further developed to account also for the comprehensive utilisation of the material inventory of a raw materials group. Building on existing approaches, such as in the area of risk, project and portfolio management, new approaches that factor in additional environmental parameters must be developed. With new models for improving pricing parameters, as used in modern approaches to the economic evaluation of mineral deposits and exploration projects, deposits could in future be geared to the market and thus optimally valued. Real option analysis is an example of this. Cooperation and participation models, for example with exploration enterprises in third countries (keyword “backward integration”) should be specifically tailored to the raw material processing industry and new concepts drafted for the area of global raw material supply chain management.

Social acceptability of technology development in the primary raw materials area should be further raised, and to this end research must be directed toward the question of what effect different institutional value and normative systems have on the performance of new technologies.

4.2 Secondary raw materials and recycling

Growing demand for raw materials of strategic economic importance poses new challenges for the recycling industry. To date, these have concentrated primarily on material flows of high significance in terms of quantities and value, from which comparatively few but high in concentration secondary raw materials have been separated. Examples are iron scrap, unmixed aluminium scrap or glass waste. Recyclables contained in very low concentrations are partially separated through sorting and treatment and are recovered in by-products or treatment waste. In some cases they are currently returned to the cycle – for example anode slurry from copper refining – or are passed back to the market indirectly diluted with the major metals. This results in losses where for example alloy elements added as steel stabilisers become
The topic of material flows/potentials should provide as comprehensive a data base as possible on secondary raw material sources, and demonstrate the opportunities and limits of a particular material flow management. Specifically, the R&D approaches of this field could be structured as follows:

- **Secondary deposits**
  Quantities and properties of the raw material inventory in landfill municipal waste, production residues, slag heaps or other old landfills in the existing infrastructure (in the sense of urban mining).

- **Current and future material flows**
  Identification and quantification of raw materials of strategic economic importance in the existing economic cycle and the prognosis for the changes in quantities and contents to be expected; identification of unused and new potential material flows.

- **Detection systems**
  Studies for the setting up and expansion of differentiated detection systems for previously used dispersed and distributed raw materials of strategic economic importance, for example separate collection systems for magnets, illuminants and certain electronic assemblies; improved separation systems; further development of sensor technology for automatic recognition.

- **Temporary raw material deposits**
  The conception and implementation of the reversible deposition of recyclables that are not yet able to be returned to the resources cycle under prevailing conditions.

The temporary deposits must ensure high environmental protection, for example protection of groundwater or the avoidance of greenhouse gas emissions. Should suitable recovery processes be available, they must be easy to dismantle under economically and ecologically acceptable conditions.
R&D approaches in the area of metallurgical extraction and purification focus on flexible processes with maximised recovery rates for multi-metal systems and on improved elemental or molecular material separation. An example of this is the development of melt metallurgical recyclables recovery processes using reductive and oxidative methods and the formation of recyclables-enriched or recyclables-reduced intermediates. In addition to these pyrometallurgical processes, the integration of hydrometallurgical separation processes into the process chain is becoming increasingly important. With highly diluted recyclables it is very important to factor-in high selectivity of the enrichment steps. Examples here are leaching, selective enrichment processes such as solution extraction, ion exchange, membrane processes or electrolysis.

The topics of material flows/potentials, treatment/separation and metallurgical extraction/purification need not be viewed in isolation, but can also be mutually dependent. This concerns for example metallurgical processing, the efficiency of which can depend greatly on previous treatment steps. The optimisation of interfaces (depth of processing) is of great importance here. The mechanical-physical treatment and remediation of high-performance materials requires relevant input materials to be separately recorded and added or that a new metallurgical process be developed.

• Product design
Recyclable construction, product labelling (also for automated identification/sorting, see above). Examples are removable electronic assemblies or rare earth-based magnetic drive and switching systems in vehicles (such as window opening mechanisms or seat and mirror adjustments) which at present are sent for shredder scrap. If appropriately labelled and easy to access, these could be separated by hand or using an automated system. The idea of recovery in product design must be appropriately established in operational and university training.

The topic of treatment/separation primarily concerns technical R&D approaches fundamentally relating to mechanical-physical processes. These include the separation of materials retaining (in some cases) assemblies, composites and alloys; the material properties originally intended are still largely retained. This is particularly the case for high-performance materials with costly manufacturing processes. Alternatively, composites or mixed waste such as slag could be broken down by tuned and metered mechanical action into their original constituents. The basic materials can thus be used directly to form new composites or for other purposes.
In order to achieve objective decision-making criteria similar to those for primary raw materials and exploration, the complementary topic of evaluation should assess alternative individual recycling technologies and approaches, or significant mutually-coordinated process combinations. This should incorporate eco-balance and economic criteria, and other aspects such as implementation opportunities or social impacts should also be factored in where appropriate.

4.3 The view from German industry

As globalisation brings ever-accelerating international division of labour, with competitors in Asia and other parts of the world, German industry’s future competitiveness depends greatly on its ability to innovate. In this respect, German industry is the driver of change. With their products, companies undeniably contribute toward climate protection, energy efficiency and future technologies. Germany is facing a series of major challenges affecting all of society, such as climate change, transformation of the energy system and increasing competition for resources. Dealing with these challenges requires appropriate technologies, processes and products which industry provides, for example:

- high-tech materials for resource-conserving mobility
- batteries for electric cars
- materials for building wind turbines
- copper and aluminium for extending the power grid
- insulating materials for making buildings energy-efficient

Examples are to be found throughout the value chain, starting with the use of resources, of raw materials, of energy. Only in this way can the products needed to solve global problems be manufactured; progress and innovation therefore remain dependent upon the availability of raw materials.

In the view of the Federation of German Industries (BDI), improving the security of raw materials in Germany demands a comprehensive approach that encompasses all the relevant areas; breaking down trading restrictions and expanding direct sources of supply must form part of this approach, in just the same way as improving access to raw materials. Just as important are the strengthening and closing of material flows, the further development of recycling, use of production waste, and the development of substitutes. To this end contributions from the various policy spheres must be better coordinated, in particular trade policy, waste policy, environmental policy and research policy. The overriding goal must then be to secure for industry access to raw materials in sufficient quantity and at competitive prices.

Research policy can contribute significantly to improving the availability of raw materials. The development of technologies to uncover illegal exports of waste, and the further development of exploration and extraction methods for investigating and exploiting domestic raw materials potential, are examples of this. The potential of, and need for, the supporting through research of other spheres of policy relevant to raw materials must be taken into account in the development of new research programmes in order to create a coherent raw materials policy.

According to the BDI, the overriding concern of industry is that the Federal Government’s high-tech strategy factors in existing and planned initiatives in Germany and Europe to improve availability of metallic raw materials, and if possible link in with these. Mention should be made in particular of the planned European raw materials innovation partnership.

In evaluating the criticality of raw materials, industry considers the results of the most recent German and European studies should apply (Angerer et al. 2009, European Commission 2010, Elsner et al. 2010, Erdmann et al. 2010).

In addition, training and education form an important part of supporting innovation in the raw materials sector, with the industrial value chain offering many progressive high-end jobs. Innovations can be promoted and developed through close ties between industry and universities and high mobility between the sectors.
In industry's view, important contributions to research for improving the supply situation in metals are:

- **Extending the knowledge base on the availability of primary and secondary raw materials**
  For example, analysis of the metal content of existing landfills, spoil heaps, production slag and by-products.

- **Further development of the extraction of raw materials from waste and end-of-life products by supporting the development of recycling and recovery processes**
  This relates in particular to rare earths and other metals used in small raw material quantities in complex products, and for which there have to date been very few recycling processes.

- **Improved utilization of metal-containing production residues**
  This requires a raw materials and processes-specific review of the value chains that can be rapidly implemented particularly by small and medium-sized enterprises through collaborative joint projects.

- **Analysis of material flows of critical metals in Europe**
  It is important to analyse what quantities of raw materials of strategic economic importance are used or occur at what points in the value adding stages and in the product lifecycle in order to identify starting points for returning to the material cycle.

- **Development of technologies and measures to prevent illegal exports**
  Considerable quantities of valuable metals are still being lost from the European material cycle through illegal exports of waste declared as spent products. This is a key weakness in export controls. Processes and technologies to improve and facilitate the uncovering of illegal exports of waste are needed.
5 Measures for programme implementation

5.1 BMBF funding priorities

On the recommendation of the Programme Advisory Committee the BMBF will direct the Call of the “Raw materials of strategic economic importance for high-tech made in Germany” programme toward increasing domestic supply of raw materials of strategic economic importance. Short, medium and long-term goals in this regard are being pursued in the supply of both primary and secondary raw materials. Specific priorities should be:

- development of concepts for the exploration of primary raw materials
- development of technical concepts for the economic use of complex ores of known deposits
- treatment of processing and production residues
- processing of end-of-life products

Some 20 to 25 years separate the last exploration work performed in Germany, at the beginning of the eighties, from current activities. At this dimension, the innovation cycle for new methods and concepts lies in exploration. The state of the art has fundamentally changed: the depth of penetration of exploration methods has increased, and quite new genetic models for new types of deposit have been developed worldwide. The fact that even in a country with a long mining tradition it is still possible to discover minable deposits is demonstrated for example by the discovery of significant tungsten deposits at Mittersill in Austria in 1967, discovered on the basis of a scientific idea. Such conceptual preliminary work forms the basis of any commercial exploration. Commercial exploration itself is not the subject of this funding programme; rather, innovative concepts for the exploration of new domestic deposits should be developed based on our knowledge of German deposits and new international findings and methods.

The long tradition of mining and exploration in the metal sector in Central Europe has resulted in known raw material deposits for which to date no suitable processing methods could be developed, as well as large amounts of tailings (treatment residues) and production residues. Further, the efficiency of treatment of complex ores, which in some cases is very low, leaves residues that contain considerable raw material potential. Even recognising that realistically a great many of these residue heaps will in the meantime have been built over or used another way, there remains great raw material potential that could be utilised with improved methods.
In the processing of end-of-life products, it is important to bear in mind that product cycles are becoming ever shorter and the products of our industry, particularly in electronics, increasingly complex. The result is an ever more complex and fast changing mix of secondary materials. The composition of these materials is far more complicated than that of primary raw materials or concentrates, and requires that special mechanical and metallurgical processing methods are developed. To date, the primary concern in secondary raw materials has been on material flows of high significance in terms of quantities and value, from which comparatively few high concentration secondary raw materials have been separated. By contrast, the emphasis here should be on secondary substances largely contained in very low concentrations in end-of-life products which to date have been recovered only in by-products or waste. For these, re-extraction methods need to be developed.

The BMBF will also use existing funding activities in the “Research for Sustainable Development – FONA” framework programme to support the implementation of the programme. The following current funding measures with further deadlines for the submission of project ideas are relevant here:

- **KMU-innovativ (SME Innovative): Resources and energy efficiency**
  Funding of innovative individual or collaborative projects to increase resource efficiency for which small and medium-sized enterprises (SMEs) will be the principal users of the outcomes

- **International Partnerships for Sustainable Technologies and Services for Climate Protection and the Environment (CLIENT)**
  Joint funding of R&D projects with international partner countries to support sustainable resources utilisation

In the BMBF “Materials Innovations for Industry and Society – WING” framework programme, resource efficiency is addressed as the central area of activity. Innovations in the materials sector mean that use of material and energy resources can be reduced in a targeted way and pollution levels lowered. Material innovations offer high potential for industrial processes, at every value-adding level, to be carried out considerably more effectively while simultaneously reducing use of resources. This can for example be achieved through using natural resources intelligently and efficiently, increasing material efficiency or extending the life of components and facilities.

A priority of the "Research for the Production of Tomorrow" framework programme is to increase resource efficiency in production. This includes funding measures to further develop technologies on raw material extraction and for efficient raw material processing. Future research focuses include for example:

- Management of cycles (using instead of selling, business models for cycle processes, concepts for global product and material cycles, holistic evaluation techniques for cycle processes, methods for illustrating, assessing and optimising production networks in waste management systems, planning processes and tools for reverse logistics)

- Development and production of recyclable products (methods and directions for the development and construction of recyclable products, improvement of recyclability through holistic lifecycle design, material alternatives and adapted manufacturing processes, production processes and materials for recyclable products)

- Recycling technologies (processes for detecting, separating and treating materials from end-of-life products, processes for separating composite materials, qualification of recycling technologies for industrial use, high-grade materials based on secondary raw materials)

### 5.2 Associated measures

As well as R&D activities, training and education are of particular importance for securing the high-tech location Germany in the long term and counteracting the skills shortage. Higher education institutions are gearing the courses they offer to the increasing demand for skilled labour and the corresponding rising demand for higher education places on raw materials-relevant courses (see Table 2).
Table 2: Time development of student numbers by subject with reference to raw materials (selected raw material-related courses, diploma, MSc, BSc totalled).

**RWTH Aachen University – students by selected courses**

<table>
<thead>
<tr>
<th>Subject</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw materials and disposal technology</td>
<td>744</td>
<td>757</td>
<td>887</td>
<td>957</td>
<td>922</td>
</tr>
<tr>
<td>Metallurgy and Materials Engineering</td>
<td>749</td>
<td>899</td>
<td>1069</td>
<td>1214</td>
<td>1315</td>
</tr>
</tbody>
</table>

(RWTH Aachen University facts and figures 2010)

**TU Bergakademie Freiberg – students by selected courses**

<table>
<thead>
<tr>
<th>Subject</th>
<th>2006</th>
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<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geotechnics and mining</td>
<td>227</td>
<td>263</td>
<td>311</td>
<td>345</td>
<td>398</td>
</tr>
<tr>
<td>Geology/mineralogy/geosciences</td>
<td>139</td>
<td>169</td>
<td>231</td>
<td>281</td>
<td>353</td>
</tr>
</tbody>
</table>

(TUBAF facts and figures 2010)

**TU Clausthal – students by selected courses**

<table>
<thead>
<tr>
<th>Subject</th>
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<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy and raw materials/raw material supply technology</td>
<td>95</td>
<td>126</td>
<td>146</td>
<td>177</td>
<td>231</td>
</tr>
<tr>
<td>Metallurgy/material sciences and technology</td>
<td>147</td>
<td>137</td>
<td>136</td>
<td>123</td>
<td>149</td>
</tr>
</tbody>
</table>

(TU Clausthal – higher education statistics)

The Programme Advisory Committee recommends further associated measures for implementing the aims of the programme to supplement research funding by the BMBF.

- **R&D infrastructure**
  R&D infrastructure on a demonstration scale should be provided and supported along the value chain, from mining through to recycling. This may be necessary to strengthen the hand of German research locations in international competition and to promote the implementation of R&D outcomes at the industrial level.

- **Ph. D. student programme to optimise interfaces in the raw material to material process**
  Training of business managers on the interfaces in the “material availability – material production – material processing – material use – material recycling” chain should be made available as part of a Ph. D. student programme. The content of the training comprises the interrelationships and technological influences in the material flow – starting from recycling-friendly product development – on material production, material use and material recycling in its entirety. Only this type of interdisciplinary education can offer a sustainable solution approach to the “interface problem” of the raw material to material process.
• **Participation in transnational calls for projects in ERA-Net ERA-MIN**
  Research topics particularly suited to European cooperation because of their transnational synergies should be handled in transnational calls for projects within the framework of the ERA-Net ERA-MIN, the objective being to support the cooperation of German research institutions and enterprises with leading European partners in transnational research associations.

• **International academic exchange**
  The internationalisation of German raw material research can be reinforced, and new partnerships with leading international research institutions and countries rich in raw materials developed, through targeted measures to support academic exchange such as cooperation with DAAD or through European Marie Curie measures. These measures should be linked with BMBF-funded research projects by subject and institution.

• **Networks and transnational centres of resource research**
  A key to efficient raw material technology research and development lies in the cooperation between leading international research centres. The opportunities should be taken of establishing transnational networks and promoting sustainable bilateral scientific and technological cooperation (STC).

• **Active co-design in the Raw Materials EIP and other European initiatives**
  Processes in the raw materials field for a European Innovation Partnership should be actively co-designed with the BMBF in order to bring-in German R&D priorities and increase benefits for German industry. Leading German research institutions should be involved in the planned Knowledge and Innovation Community (KIC) of the European Innovation and Technology Institute (EIT) on the topic of raw materials. Research collaboration with France could form the starting point for joint European activities in the coming “Horizon 2020 EU” research programme.

• **Raising the acceptability of domestic raw material extraction**
  Targeted measures to create awareness of the raw material problem and promote acceptance by the public of environmentally-responsible domestic raw material extraction should be introduced in a timely manner. Only in this way can potential reservations and resistance, that could jeopardise the economic exploitation of the results of the R&D effort, be dealt with.

• **International conference format**
  To raise public awareness and international networking of German research on raw material technologies, the Programme Advisory Committee recommends greater participation in established international conferences or the development of its own international conference format. In this way the guiding principle of sustainable development in the raw materials sector should receive international impetus.
Abbreviations and glossary

**AWI (Alfred Wegener Institute for Polar and Marine Research):**

The Alfred Wegener Institute is the Helmholtz Centre for Polar and Marine Research. It coordinates polar research in Germany and provides important infrastructure for science, such as research ships that are also used in seabed exploration for marine raw materials. The Institute is headquartered in Bremerhaven and has over 900 employees. www.awi.de

**BGR (Federal Institute for Geosciences and Natural Resources):**

The Federal Institute for Geosciences and Natural Resources (BGR) is the Federal Government’s central geoscientific advisory agency and comes under the portfolio of the Federal Ministry of Economics and Technology (BMWi). The German Mineral Resources Agency (DERA, see below) also has its headquarters at the BGR. www.bgr.bund.de

**CLIENT (BMBF funding priority):**

The “International Partnerships for Sustainable Technologies and Services for Climate Protection and the Environment (CLIENT)" funding priority forms part of the BMBF’s "Research for Sustainable Development – FONA" framework programme. The focus of CLIENT is on the research and development of adapted sustainable technologies and services together with partners from Brazil, Russia, India, China, South Africa and Vietnam. These will be implemented as prototypes or pilot applications in the areas of climate change, resource use, land management and water management. www.fona.de/client

**Critical raw materials (raw material criticality):**

Raw materials are termed critical raw materials when their supply situation could prove critical to industry in the medium to long term. Contributing factors in criticality are particular supply risks such as high reliance on imports or a raw material monopoly in a few producer countries and the raw material-based vulnerability of the economy, i.e. the fragility of the economy in the event of problems in the supply of raw materials due to a lack of substitution options or limited recyclability. Studies by the European Commission and the KfW Banking Group identified for example critical raw materials for the EU (the EU-14) and for the German economy (see also Figure 3, Erdmann et al. 2011 and European Commission 2010).

**demea (German Material Efficiency Agency):**

demea is commissioned by the Federal Ministry of Economics and Technology (BMWi) to advise enterprises on the importance of raw material and material efficiency and to support them in finding and exploiting potential savings to increase their profitability and competitiveness. www.demea.de

**DERA (German Mineral Resources Agency):**

DERA is the central information and advisory platform for mineral and energy raw materials at the BGR (see above). DERA is primarily concerned with raw material availability and supply situations, raw materials potential and resource efficiency. www.deutsche-rohstoffagentur.de

**EIP (European Innovation Partnership):**

The European Commission’s Europe 2020 strategy is supported by various flagship initiatives. One of the aims of the Innovation Union flagship initiative is to develop European Innovation Partnerships (EIP) that bring together public and private sector players at EU, national and regional level in order to address major social challenges through innovation and to exploit new markets for European enterprises. The Raw Materials EIP proposed by the European Commission is targeted at the sustainable supply of non-energy raw materials for a modern society. Elements of this innovation partnership should for example include the demonstration of innovative pilot plants for raw material extraction, processing and recycling, and the search for replacement materials for at least three key applications of critical raw materials. (COM(2010) 546, COM(2012) 82), http://ec.europa.eu/research/innovation-union http://i3s.ec.europa.eu/commitment/43.html
EIT (European Institute of Innovation and Technology):

The goal of the EIT is to support the competitiveness of Member States by bringing together the outstanding higher education institutions, research centres and enterprises that address the larger social challenges. As part of “Horizon 2020”, the EU’s framework programme for future research and innovation, the EIT will be expanded by six new transnational innovation centres in public-private partnerships known as Knowledge and Innovation Communities (KICs). From 2014, one of the new KICs is to focus on the topic of raw materials (sustainable exploration, extraction, processing, recycling and substitution of raw materials). http://eit.europa.eu

ERA-NET ERA-MIN:

The remit of the ERA-Net Industrial Handling of Raw Materials for European Industries (ERA-MIN), launched in November 2011 with France (CNRS) as lead agency, is to coordinate national R&D activities in the mining, recycling and substitution of non-energy raw materials, such as minerals for construction and industry and metal raw materials. In addition to Germany and France, to date Finland, Greece, the Netherlands, Poland, Portugal, Romania, Sweden, Spain and Hungary are represented in ERA-Net. United Kingdom, Italy and Moldavia are associated partners, and further partner countries are expected to join.

Planned activities include compiling information on the institutions, national strategies and support programmes of participating countries in the raw materials field and the identification of opportunities for international cooperation. ERA-MIN, together with stakeholders, is developing a strategic research agenda for non-energy raw materials which will form the basis for the joint funding of R&D projects. ERA-MIN is supported in the 7th Research Framework Programme for Research.

ETP-SMR (European Technology Platform on Sustainable Mineral Resources):

The European Technology Platform on Sustainable Mineral Resources (ETP-SMR) is an industry-supported initiative to modernise the European mineral raw materials industry through research and innovation.
Priorities include the securing of raw material availability, support for exploration activities in Europe and the development of sustainable production technologies.
www.etpsmr.org

FONA (Research for Sustainable Development):

The "Research for Sustainable Development – FONA" framework programme of the Federal Ministry of Education and Research (BMBF) integrates the entire research process, from basics through to application, in order to provide decision-making bases for future-oriented commerce. It presents the conceptual framework for the BMBF’s sustainability-based research funding over the period 2010 to 2015 in which more than two billion EUR of funding is to be provided for the development of sustainable innovation. A central activity of FONA is "Sustainable management and resources" which incorporates the existing R&D programme and in which special raw material technologies funding priorities are already being implemented (for example r², r³, CLIENT, SME Innovative, refer to those).
www.fona.de

GEOMAR:

The GEOMAR Helmholtz Centre for Ocean Research Kiel is one of the leading institutions in the area of ocean research in Europe. The Institute is tasked with studying the chemical, physical, biological and geological processes in the ocean and their interaction with the seabed and atmosphere, and includes for example ore formation at the bottom of the oceans. The Institute has approximately 750 employees.
www.geomar.de

GFZ (German Research Centre for Geosciences):

The GFZ Helmholtz Centre in Potsdam is the national research centre for geosciences, studying “System Earth” globally and the geological, physical, chemical and biological processes at work within and on the surface of the Earth, and performing fundamental research on the securing and environmentally-responsible extraction of natural resources. The GFZ has over 1000 employees.
www.gfz-potsdam.de

HIF (Helmholtz Institute Freiberg for Resource Technology):

The Helmholtz Centre Dresden-Rossendorf and the TU Bergakademie Freiberg bring together their expertise and infrastructures at the Helmholtz Institute Freiberg for Resource Technology (HIF). The goal is to provide new technologies for the exploration, extraction and use of raw materials for industry. Other focuses include the training of skilled workers in the raw materials sector and the support of training and education for foreign skilled and management staff in the resource sector. The HIF was founded in 2011 with funding from the BMBF and the Land Saxony.
www.hzdr.de/freiberg

High-tech metals:

High-tech metals are those that are of particular importance for the production of future-oriented technologies such as energy and environmental technologies, information technology and electric mobility. These include for example the rare earth metals (see below) and other metals which are produced in only small quantities compared to the major metals such as iron, aluminium or copper, but that are essential to high-tech areas. Demand for these metals can rise sharply as a result of developments in individual technologies, such as power generation from wind turbines, resulting in increased risk to supply. As a rule there is high reliance on imports for these metals and they are of strategic economic significance to Germany (see below).

HZDR (Helmholtz Centre Dresden-Rossendorf):

The Helmholtz Centre Dresden–Rossendorf conducts research on obtaining and improving resources in the fields of health, energy and matter. Large-scale facilities, such as the Dresden High Magnetic Field Laboratory, are used for example to develop innovative materials. The HZDR has around 900 employees.
www.hzdr.de
**KICs (Knowledge and Innovation Communities):**

KICs are transnational innovation centres in public-private partnerships at the European Institute of Innovation and Technology (EIT, see above). A KIC on sustainable exploration, extraction, processing, recycling and substitution of raw materials is to be established in 2014 within the new “Horizon 2020 European” framework programme.

**KMU-innovativ (SME Innovative):**

With the SME Innovative funding initiative launched in 2007, the BMBF is pursuing the goal of consolidating the innovation potential of small and medium-sized enterprises (SMEs) in the area of cutting-edge research and making research funding more attractive as part of its specialised programmes. One of the funded technology fields within the framework of the SME Innovative is “Technologies for resource and energy efficiency”. On the basis of of bi-annual deadlines for submission, funding is provided to innovative R&D projects by SMEs working with other enterprises or research institutions that contribute towards increasing resource and energy efficiency. www.kmu-innovativ.de

**MatRessource (BMBF funding priority):**

In addition to the more efficient use of raw materials, the aim of MatRessource (Materials for resource-efficient industry and society) funding priority in the “WING” framework programme (see below) is the substitution of strategic metals and extending the life of components and facilities. Increasing resource efficiency through material innovations should contribute to permanently reducing reliance on the import of raw materials, improving international competitiveness by reducing energy and material costs and relieving environmental pressures.

**Primary raw material:**

Raw material that is extracted directly from natural resources (such as ore) rather than from material residues (see also Figure 1).

**ProgRess (German Resource Efficiency Programme):**

The Federal Government’s German Resource Efficiency Programme (ProgRess) gives an overview of existing activities, approaches and measures to increase resource efficiency. It concentrates in the first instance on abiotic, non-energy raw materials and on the material use of biotic raw materials, and as part of this is developing 20 approaches to the sustainable use of these raw materials. http://www.bmu.de/themen/wirtschaft-produkte-ressourcen/ressourceneffizienz/progress-das-deutsche-ressourceneffizienzprogramm/

**r² (BMBF funding priority):**

The BMBF funding priority “r² – Innovative Technologies for Resource Efficiency – Resource-Intensive Production Processes”, part of the “FONA” framework programme (see above), focusses on raw material-related industries with high material usage because considerable leverage can be achieved here to increase raw material productivity, for example in the metal and steel, chemical, ceramics and construction materials industries. In the period 2009 to 2013 a total of 22 collaborative R&D projects are being supported by enterprises in the business sector together with research institutions, with total funding of approximately EUR 38 million plus a further EUR 18 million provided by the enterprises involved. www.r-zwei-innovation.de
sensitivity of the national economy with respect to supply problems (substitutability, recycling rates etc.). Resulting largely from political changes, the build-up of new primary and secondary productions, or by rapid technological change, and often triggered by sudden price spikes impacting on the raw material supply control loop (see Figure 4), a critical review occurs every three years.

**Raw material productivity:**

Raw material productivity is an indicator for assessing the raw material consumption and raw material efficiency of a national economy. It derives from the quotient of [total raw material or material consumption] and [gross domestic product], i.e., raw material productivity can be increased either by reducing raw material input for the same value-added, or by increasing value-added from set raw material input. The indicator is used for example in the Federal Government’s National Sustainable Development Strategy “Perspectives for Germany”. The aim is to double raw material productivity by 2020 (compared with 1994 baseline).

The “raw material productivity” summary indicator is also criticized by the scientific community, since all raw materials are given equal weight without any raw material value hierarchy being factored in. Considerable leverage can result from the use of raw materials of strategic economic importance (see below) in only small quantities. For example, the raw material efficiency of energy raw materials can be raised by modern measuring and control technology, but with a corresponding demand for technology raw materials (Wagner and Wellmer 2009).

In addition, the previous method for determining raw material productivity is based on the measurements of the domestic raw material extraction and imported raw materials, together with semi-finished and finished goods. Substituting domestic production or importing goods at higher stages of processing yields a calculated increase in raw material productivity, although in fact there is no saving in resources. Including this additional material demand in the countries of origin in the form of so-called raw material equivalents (“raw material backpacks”) would further put into perspective the previously positive development of the indicator (Buyny and Lauber 2009).
**Resource efficiency:**

The generic term resource efficiency brings together measures for the conservation and efficient use of natural resources (including raw materials). These include primarily increasing efficiency in the extraction of raw materials, reducing the use of materials in processes and products, extending the productive life of products, cycling of raw materials (recycling) and the substitution of scarce resources.

**Secondary raw material:**

Raw material extracted by treatment processes from material residues resulting from production or consumption (for example waste, end-of-life products) in order to be re-incorporated into the economic cycle (see also Figure 1).

**WING (Materials Innovations for Industry and Society):**

The BMBF has since 2004 been promoting the development of new materials, material-based manufacturing and processing technologies and the interdisciplinary nanotechnology research field as part of the “WING” support programme. The programme focuses on the three headline objectives:

- strengthening the innovative capability of enterprises
- taking account of the needs of society
- use of research and technology for sustainable developments

This provides a cornerstone for greater industrial competitiveness, resource- and environment-conserving technologies, and the creation or preservation of high-value jobs in Germany.

Figure 14: Old heaps from copper extraction as a potential source of raw materials (source: Maike Hauschild, PtJ).
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