ENTWICKLUNGSFONDS SELTENE METALLE

ESM Survey

"Critical Materials in Switzerland"

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Metalle ESM

December 2015

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Survey runtime:
13.10.2014–05.01.2015
Number of people asked to participate: 130
Number of respondents: 32

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1. EXECUTIVE SUMMARY

The Swiss Foundation of Rare Metals (Stiftung Entwicklungsfonds Seltene Metalle, ESM) has conducted a survey about "Critical Materials in Switzerland" amongst members of the Swiss Industry. The term "criticality" has gained more and more importance over the last years, meaning a lacking supply security of a certain raw material, but also suggesting wider implications such as a general limitation or a specific political or ecological impact caused by mining and processing.
Some materials functions are increasingly important in innovative products for various industrial sectors such as energy, construction, transport, communication technologies or health. Although mostly only small amounts of critical elements are contained in a material or component, sometimes a company may face problems with the supply or the high price volatility of specific critical element. Based on a survey which was already carried out in The Netherlands three years ago, this report presents answers from industrial stakeholders from various important sectors in Switzerland. In total, the survey contained 31 questions, divided in 4 sections:

1. Companies, their products and used materials
2. Perception of criticality
3. Influence of criticality for the industry
4. Critical elements in the company

For most of the about 32 companies answering the questionnaire, criticality is related to supply insecurity of the materials they need. In most cases, the critical materials did not represent more than 10 % of the materials used for a product; in a few cases, the amount of such elements was up to 30 %. The economical factors which relate to the increased demand for critical elements are more pronounced than geopolitical factors. Considering the wide spectrum of materials processing companies which were asked in this survey to achieve specific properties and functions (heat treatment, joining, layers & coatings), higher prices or price variations (metal surcharge) may affect the prices of components, e.g. for those companies dealing with catalysts or magnets. The exchange with suppliers is the main source used to for information about critical materials. However, companies are also using other sources, such as their networks with clients and. Most of them indicated to mitigate supply and volatility risks by using multiple suppliers, while many also see a more efficient use of the materials and increased material substitution as valuable possibilities. Only a few participants stock-pile critical materials to meet possible supply disruptions.

A decision for a development of new materials, changes or adaptation in the processing or in case that no substitute is available, the creation of new process technologies or even other ways to achieve the desired function has to be taken long before the situation becomes critical. Materials science and engineering is still a long-term investment, and smaller companies may even not be able to afford such an investment. Many products today are not designed for re-use and recycling. However, companies see both issues – materials development and design of materials and components – directly related to the production and processing steps of their products. To be more and earlier informed, some companies perceive the use of databases covering data and development trends of raw materials as a possible tool to meet the problems posed by critical materials. Companies are also considering the possibility to gather more insight into the quantities of critical materials in all products of the company and training personnel in in this field to gain more knowledge. Regarding the content of a database, participants of the survey indicate regulatory issues regarding critical elements, followed by their properties, economic and financial evolution.

The economic situation on critical materials has improved for companies in 2015, as prices are low and materials are available. Nevertheless, the geopolitical situation can quickly change, and industries as well as universities aiming to follow medium- to long-term research should be motivated to make "material criticality" an integral part of corporate Risk Management.

2. INTRODUCTION

In 2012, the Materials innovation institute (M2i) with a team of Derk Bol and Hans Christ and the Netherlands Organisation for Applied Scientific Research (TNO) with Ton Bastein, Niels van Loon, and Gerrit Oosterhuis conducted a survey with the title „Critical materials and The Netherlands – a view from the industrial-technological sector“ (Bol and Bastein 2012). Knowing Derk Bol from the EU programme ERAMIN, the opportunity of conducting a survey with similar questions was discussed, and ESM was allowed to use the questions for its own survey in Switzerland.

Switzerland has about 8.2 Mio and the Netherlands about 16 Mio inhabitants. The Gross Domestic Product (GDP) in the year 2014 is for the Netherlands is 798.6 billion $ and for Switzerland 472.8 billion $ which is a similar amount per inhabitant (Switzerland is the world-wide number 9 in gross domestic product per capita (PPP); Netherlands number 14) (IMF 2014). The Dutch industrial activity, including mining, generates about 20 % of the GDP and is dominated by metalworking, oil refining, chemical, and food-processing industries. Construction amounts to about 6 % of the GDP, while in Switzerland the pharmaceutical industry is dominating and is present with companies in different industrial sectors. About 40 % of the population is employed in the industry, trade and handicraft (which is considered the "secondary sector"). This sector includes the machine and metal industry, watch industry and the textile industry (BFS 2015).

With these similarities in size and economic performance, but differences in industrial core areas, it was interesting to highlight the view of industry regarding critical materials and to compare answers from both countries. For the study at hand, about 130 Swiss companies were contacted based on a list of companies which were highly interested in materials research and development (interest in conferences and seminars, interest in the CCMX activities). From these companies, 32 responded to the survey. In the Netherlands, 30 companies have participated in this research representing a cross section of the Dutch industrial-technological sector.

3. SWISS INDUSTRY

Switzerland is a country known for high precision industry products reflecting a very broad field of machining, metals and the high-tech materials industry for various industrial sectors like transportation, energy, construction, medical and health applications, etc. Some figures from large industrial associations may characterise the importance of such industrial sectors. The Swiss MEM Industry which is represented in Switzerland e.g. by the Swissmem association and SWISSMECHANIC (together over 2400 companies) covers machinery, electrical and metal companies with about 330'000 employees in 2014 and about 15 billion CHF return on investment, accounting for 9 per cent of the overall Swiss value creation (Swissmem 2015). Both associations represent a very large number of companies in this high tech industrial sector which covers mechanical and process engineering, conveyor and storage technology, precision tools, equipment for apparatuses, valves, pumps and systems, and for compressors, compressed-air and vacuum technology, welding and cutting technology, environmental technology, filling and packaging technology, security and ærospace technologies, electrical appliance industry (electrical domestic appliances and power tools), textile machinery, photonics, plastics processors and plastics processing machinery, die-casting, and many more. Furthermore, high value-added sectors such as the watch-making industries, precision instruments, medical device technologies, the semiconductor and micro-nanotechnology based sectors are well established in Switzerland. Based on data provided by the Federal Statistics Office, the secondary sector of the economy including the value from production to the finishing of products showed about 90'344 enterprises in 2012 in Switzerland with more than 1 million employed persons, which is about 12 % of the Swiss population and about 25 % of the working population (BFS 2015). This industrial production sectors are therefore very important for the working place Switzerland and for the exportation economy as about 80 % of the products are mainly exported to European countries (main import/export from/to Germany followed by Italy and France) and abroad (main export USA followed by USA, import equal). The trade surplus in industrial machinery was at about 7'822 million

In the statistics of Switzerland (GTAI 2011) , the following industrial sectors mentioned in the secondary sector show the largest groups of employees, when discussing the implication in critical element (other big industrial sectors in Switzerland are construction and civil engineering, and manufacturing of wood, paper and printing products) :

- Production of data processing equipment and computers and watches with 2300 companies and 112'000 employees
- Manufacture of fabricated metal products with 8'300 companies and 106'000 employees
- Food and tobacco industry with 3'400 enterprises and 88'500 employees
- Energy supply with 700 companies and 29'500 employees (GTAI 2011)

Some of these branches are especially susceptible to materials criticality.

CHF in 2013, in the field of tool-making and mold-making industries and machinery parts about 4'500 million and high precision instruments and watch industry has about 7'689 million CHF in trade surplus. Many of these products are based on metals, of which Switzerland imported an overall value of 12'062 million CHF in 2013 (Tercero Espinoza 2012).

4. CRITICAL MATERIALS IN EUROPE AND SWITZERLAND

The expressions "critical raw materials" or "criticality" are used since Europe and other industrialized countries which have no or only few resources in raw materials were faced by export restrictions for materials they needed for their innovative products especially in the industry sectors of energy, transportation and communication, all three highly important for the economy of the countries and the wealth of their population.
According to Fraunhofer Institute for Systems and Innovation Research (ISI), criticality is a relative concept which has at least two dimensions of risks: the general risk of supply interruptions and of its impact, e.g. on the general economy (Tercero Espinoza 2012). Thus raw materials are not critical in an absolute way, but they are critical to somebody (for some reason or set of reasons) at some point in time. The risk of supply interruption may be due to geopolitical reasons but also due to the fact, that the economy is using more of the material than the resources can supply and it might become too difficult, too expensive or even too harmful for the environment to obtain and use the materials which are needed for the economy. If in this case also no substitutes of such materials are available to replace the same functions and properties in a component or a product, this adds to the criticality of the material, other options have to be considered. The European Union identified the risks in the supply of raw materials such as rare earth elements in the negative impact on their economic growth. In 2010, a first criticality analysis for raw materials was published in Europe by the Ad-Hoc Working Group on Defining Critical Raw Materials, a subgroup to the Raw

Materials Supply Group, which is an expert group of the European Commission. There were 14 critical raw materials identified from a candidate list of 41 non-energy, non-food materials. In 2013, a follow-up study was conducted with 54 raw materials instead of 41 using the same quantitative methodology as in the previous 2010 study, applying two criteria - the economic importance and the supply risk of the selected raw materials. The following assessment components have been used in both studies (EC 2014):

– “ECONOMIC IMPORTANCE: this analysis is achieved by assessing the proportion of each material associated with industrial megasectors at an EU level. These proportions are then combined with the megasectors’ gross value added (GVA) to the EU’s GDP. This total is then scaled according to the total EU GDP to define an overall economic importance for a material.”
– “SUPPLY RISK: in order to measure the supply risk of raw materials, the World Governance Indicator (WGI) was used as well as other factors which are finally considered to arise from a combination of (i) substitutability, (ii) end-of-life recycling rates and (iii) high concentration of producing countries with poor governance. The WGI indicator takes a variety of influences into account such as voice and accountability, political stability and absence of violence, government effectiveness, regulatory quality, rule of law or control of corruption.”

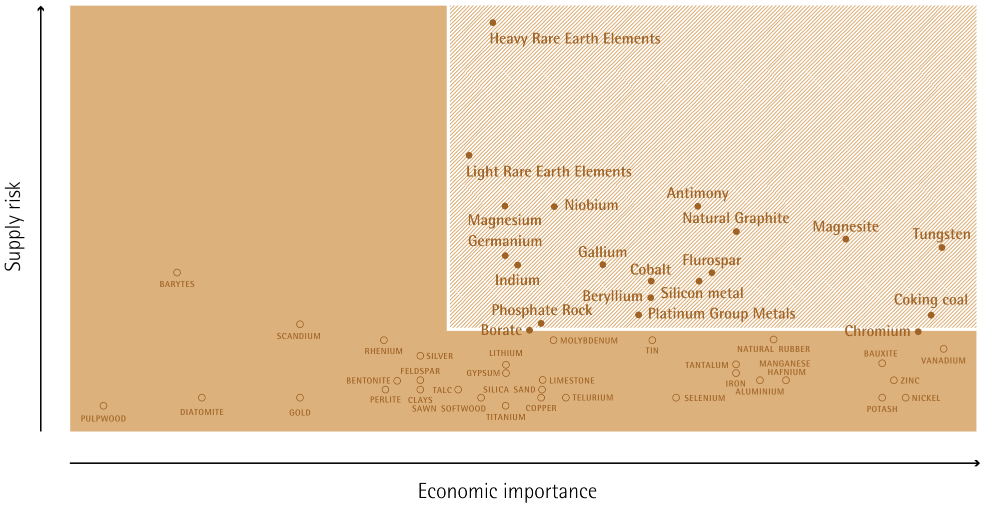
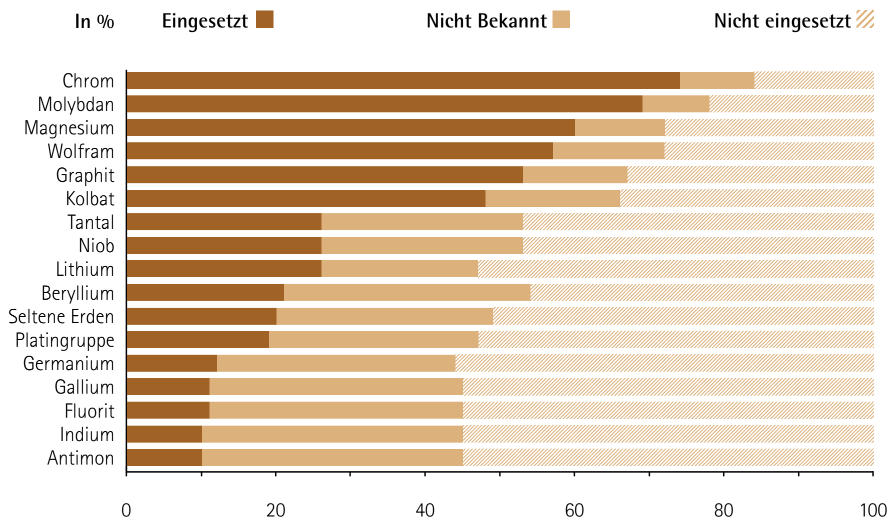


Figure 1: **Overall results of the 2013 EU criticality assessment.** The critical raw materials are highlighted in the red shaded criticality zone of the graph *(EC 2014, p 3).*

The list includes 13 of the 14 materials identified in the previous list of 2011, with only tantalum moving out of the list (due to a lower supply risk). Six new materials appear on the list: borates, chromium, coking coal, magnesite, phosphate rock and silicon metal bringing the number up to 20 raw materials which are now considered critical by the European Commission. The other 14 raw materials are: antimony, beryllium, cobalt, fluorspar, gallium, germanium, indium, magnesium, natural graphite, niobium, platinum group metals, heavy rare earths, light rare earths and tungsten (EC 2014). ESM is especially interested in elements like chromium, antimony, beryllium, cobalt, gallium, germanium, indium, magnesium, niobium, platinum group metals, heavy rare earths, light rare earths and tungsten, which are important in the use of industrial products in Switzerland. A study of Swissmem in 2010 showed that 75 % of the Swiss MEM (machining, energy and metallurgy) industry are using materials regarded as "critical" ((Kohl 2010), see also Figure 2).

The supply risk analysis in (EC 2014) shows the dominance of China in the world primary supply of raw materials candidates and the critical materials candidates as well. The European Commission had the aim to contribute to the industrial policy to raise the awareness of a certain dependency on critical materials for which the supply chain is

Figure 2: **Critical materials used in the Swiss MEM industry** *(in % of companies using at least one of these materials)*, Kohl (2010).



sensitive to disturbance and because of this are very volatile in their pricing. One of the countries with trade barriers was China, controlling 97 per cent of global rare earth production. Due to the supply problems for rare earths and other so-called “critical elements” in the years 2008 and following, the USA and Europe realized that the new technologies in Europe auch as in green energy or communication and by this the industry in these countries were depending on a reliable supply chain with non-volatile prices for their raw materials.

Especially in the energy sector, which has passed a dramatic change from very conventional coal and nuclear power based generation of electricity towards more decentralized power generation by wind and solar energy is dependent on materials containing rare earth (REE) and other critical elements. The research undertaken by the University of Augsburg, in the groups of Armin Reller and Volker Zepf together with BP about „Materials critical to the energy industry“ (Achzet et al. 2011) provides an overview of 23 materials including cadmium, chromium, cobalt, copper, gallium, germanium, indium, lithium, molybdenum, nickel, niobium, palladium, phosphorus, platinum, potassium (potash), rare earth elements, rhenium, rhodium, silver, tellurium, tungsten, uranium, and vanadium. Some of these materials have supply chains which are vulnerable in view of the risk to the sustainability of each pathway, and it

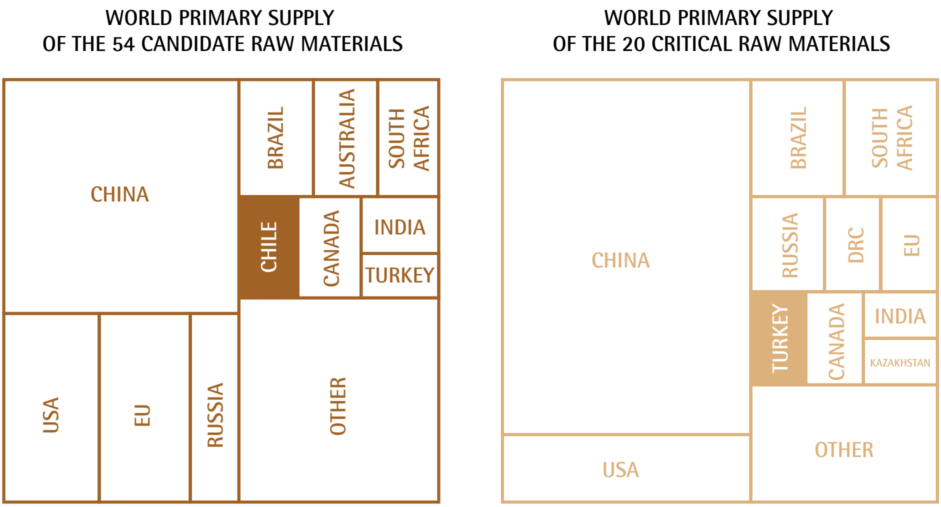


Figure 2 : **Main producers of critical raw materials** *(EC 2014, p 4).*

shows that is important now to discuss how existing energy pathways can be maintained and new ones can be created. A picture in this book also indicates the enormous increase in the number of elements that are used in the last 20 to 30 years to enable functions that are crucial for certain products (see Figure 3).

The demand for lower-carbon energy decreases on one hand the CO2 and is by this more environmental friendly; on the other hand new materials for new generations of technologies require the mining of partially exotic raw materials which are difficult and expensive to explore. The mining countries mostly do not have an environmental and employee law standard comparable to Europe. In addition, new energy forms like photovoltaics (PV), which have been primarily based on silicone, are demanding more flexible polymer based forms, and need higher output. Therefore companies are looking for elements like cadmium, gallium, germanium and tellurium or for indium tin oxide (ITO) layers to improve optical and electrical properties and to achieve a higher efficiency in thin film photovoltaic devices. These materials are not only rare and critical in their supply chain, but also critical from an environmental perspective. Other power sources like wind turbines need magnets made of rare earth metals, particularly neodymium iron boron (NdFeB), to create the strong magnetic fields in permanent magnet motors. To improve the performance of such magnets, small amounts of Dysprosium are needed.

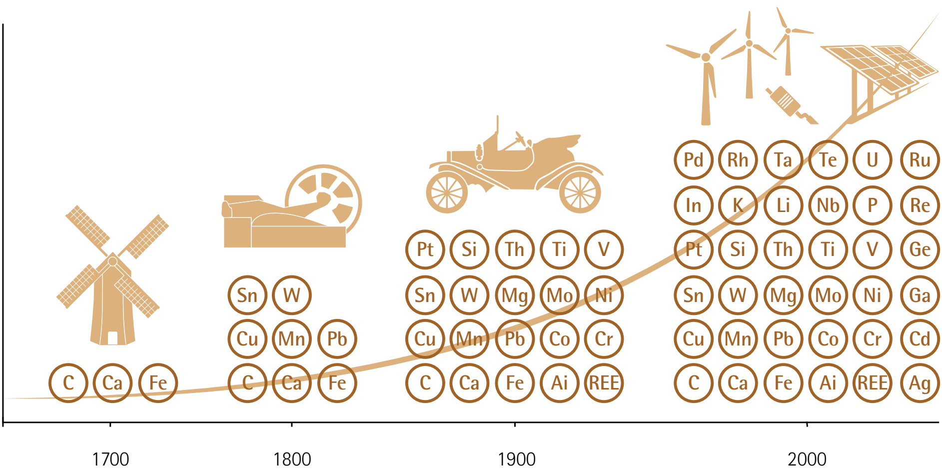


Figure 3 : Elements widely used in energy pathways. N.B. Position on the time axis is indicative only (Achzet et al. 2011, p 6).

A permanent magnet direct drive wind turbine needs 0,5 tons per Megawatt (MW) of NdFeB magnets or 0,2 tons/MW of neodymium (Reller 2013). This means that in Peak times (highest prices) like in 2011–2012 (see figure 4) neodymium of a value of 50'000 $ is needed to build a permanent magnet direct drive wind turbine producing 1 MW. In order to increase the performance, Dysprosium is added to the magnetic material which in peak times was at about 3000 US$ per kg (Wiley 2014).

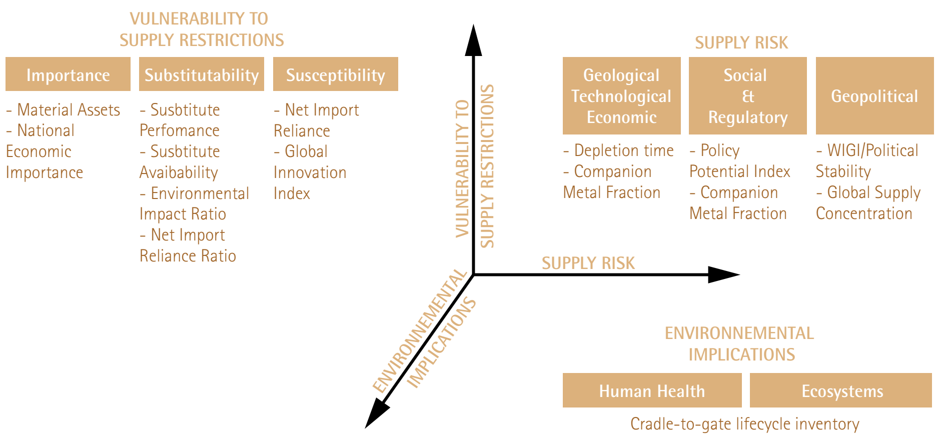
These REEs like Neodymium and Dysprosium are supplied by up to 97 % by China. Like in the case of neodymium, the extraction and the separation of many of these critical elements is related with toxic waste products which lead to the further issue of criticality of such elements relating to environmental and legal issues (Grædel et al. 2015). In the energy sector also the storage of energy e.g. in batteries is strongly dependent on critical elements like Lithium, still available but mainly in one region (Chile, Argentina, Bolivia) or Lanthanum used in the anodic material of nickel-metal hydride batteries. The demand for Lanthanum can increase with the growing request for hybrid automobiles, although Lithium batteries have gained a high interest and the activity in publications and patents has increased strongly in the last years – also in Switzerland (Thielmann

Figure 4: **Neodynmium price history** (IET 2015).

Table 1 : **Criteria for Criticality according to** (Achzet et al. 2011).

CRITERIA FOR	H	M	L
RESERVES	Reserves-to-production ratio (R/P) < 20 years *or* R/P < 100 years but semi-monopolistic production	R/P = 20-80 years *or* uncertain data	R/P > 80 years *and no* monopolistic situation
TRADE	Element *not* traded on metal exchanges *and* semi-monopolistic production (see below)	Element *not* traded on metal exchanges *or* semi-monopolistic production *or* uncertain data	Traded on metal exchanges *and no* monopolistic production
ECOLOGICAL IMPACT	Element is toxic *or* ores contain low-grade toxic or radioactive substances that might get enriched during processing *or* risk of bioactivity is not refuted	Low toxicity known *or* uncertain data *or* toxicity has been put/is in the process of getting into jurisdictional context	No toxicity *and* no handling problems known
PROCESSING	Element is produced as by-product	Element is main product *and* complex refining technologies are required *or* uncertain data *or* element produced as co-product	Element is main product *and* technology proven
SUBSTITUTABILITY	*No* substitute on materials level available *or* substitute available but itself considered critical	Substitute available with degradation in perfomance *or* no substitute available on materials level but on systemic level (e.g. wind turbine without REEs)	Substitute available
RECYCLABILITY	*No* recycling technology in mass operation *and* material concentration in end-of-life product low	Recycling technology in place *and* logistics as limiting factor *or* uncertain data	Recycling technology in place *and* global recycling rate > 50%

Figure 5 : **The three dimensions of criticality according to** (Grædel et al. 2015).



2010). A typical hybrid automobile battery for a medium sized vehicle requires currently about 10 to 15 kg of lanthanum. Due to the high costs to extract the other lanthanides a "mischmetal" with more than 50% of lanthanum is used instead of pure lanthanum (Hammond 2000).
Use a criticality matrix with criteria for various important topics in the value chain of a product, starting with reserves of elements necessary for materials used in energy producing, consuming and storing productions and for each of these six fields the criticality of elements can be classified as high, medium and low. [Grædel et al. 2015] add environmental implications as third dimension of criticality besides vulnerability and supply risk.

An important observation is that if one combines the information on reserves (not resources) and trade, which are the two important keywords for criticality in many publications only three of the twenty three elements (incl. all REE) are of really high criticality: niobium, rhenium and tungsten. On the other hand metal elements like platinum, palladium, molybdenum or chromium and indium are difficult to substitute and therefore critical for maintaining functions that these elements offer in various materials and components.

5. SURVEY

How do these critical materials influence the industry in the Netherlands and in Switzerland with their different spectrum of important products? In 2010, a preliminary report on Critical Materials in the Dutch Economy (CBS 2010) was published and an estimation was made for which products groups and by this industrial sectors critical elements could have an influence. These were:

- Basic Materials and pre-Products:
  Construction materials, basic metals and metal products
- Mechanical Engineering Industry: Machinery and Equipment
- Consumer goods /Communication: Office appliances, computers, electrical appliances
- Precisions Mechanics: Medical, precision and optical appliances
- Transportation: Cars and other vehicles
- Energy: Electricity and gas supply

In the first three industrial categories, the manufacturing system engineering has the highest importance for Switzerland, followed by the manufacturing of medical and optical devices, the chemical and food industry (see (BFS 2015)). In comparison with the Netherlands, basic materials and pre-products do not have the same importance as in Switzerland, but our country is more focused on the middle and the end of the processing and value chain.

5.1 Companies, their products and materials used

In total, the survey contained 31 questions which are listed with the detailed answer in the Annex.
The first six questions concerned products and materials use in the companies:

Q1 – What are the 5 main products provided by your company?
Q2 – What role do materials play in your company?
Q3 – If decisive or important: is your company active in materials R&D?
Q4 – If no, do you "buy" R&D from external sources?
Q5 – At which stage of a product cycle is your company active in materials?
Q6 – Please indicate your company's main needs in the development of new materials.

The first question about the main 5 products was needed to establish a better knowledge about the company's products. The 29 companies which answered this question show a high diversity in products which are summarized in the following categories:

- Materials and semi-finished products ranging from metals and alloys to polymers (no further indication for the application): 9 companies from which 3 companies are strongly related to chemicals, doping materials and polymers
- Products for construction/architecture, sanitary application, escalators, heating systems, power tools: 8 companies
- Heat treatment, joining, layers & coatings: 6 companies
- Medical devices: 3 companies
- Machinery in combination with textile: 1 company
- Watches: 1 company

Materials which were mentioned range from brass, stainless steel, hard metals and tungsten carbide, materials for magnets (SmCo) to aluminium and titanium alloys and

phases which can be grouped as metastable hard coatings used to improved the wear resistance, ceramics based on oxides which are important material for various other linear and non-linear optical applications. Some critical elements that can already be highlighted from this list are chromium for steel and hard coatings, samarium and cobalt in magnets, lithium in oxide single crystals, and tungsten in hard metals and coatings.
In question 5 (Figure 9) about the stage of a product cycle in which the company is active in materials (multiple choice), 80.6 % of the answers mentioned semi-finished products, followed by finished products (71 %), formulation and processing (64.5 %), applications (54.8 %) and raw materials (45.2 %), which means that many of the companies which were asked are active in various steps of a value chain which as the whole is shown in Figure 6.

67.7 % of participants (31 answers) stated that materials play a decisive role in their company, and 32.3 % assessed the role as being important (questions 2, 3 and 4 – see Figure 8, Figure 9 and Figure 10). From these companies, again 67.7 % mentioned that the company is active in materials research and development (R&D). Out of 19 participants, 11 stated that they buy or use R&D from external sources.

Figure 6:
Answers on question 5.

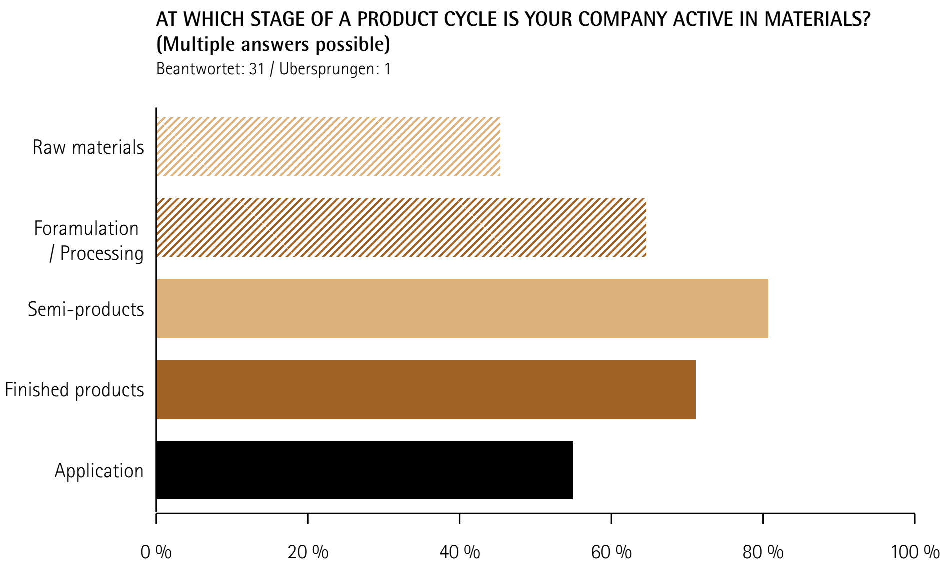


Figure 7:
Materials in the value chain.

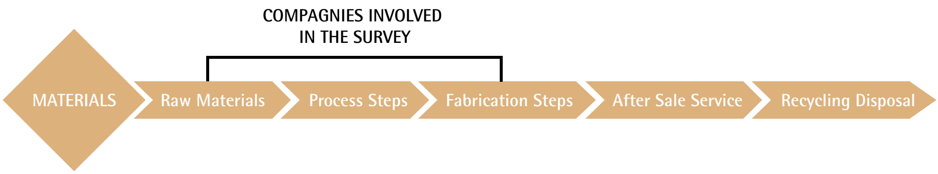


Figure 8:
Answers on question 2.

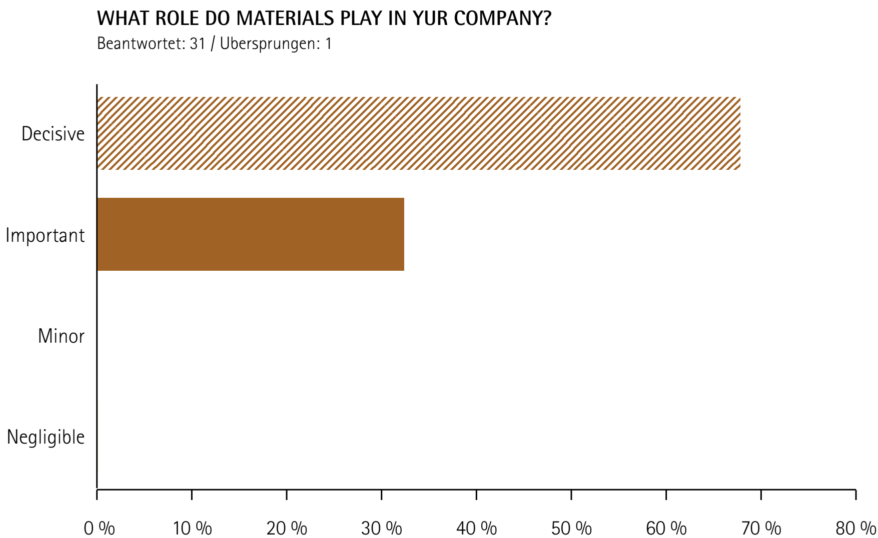


Figure 9:
Answers on question 3.

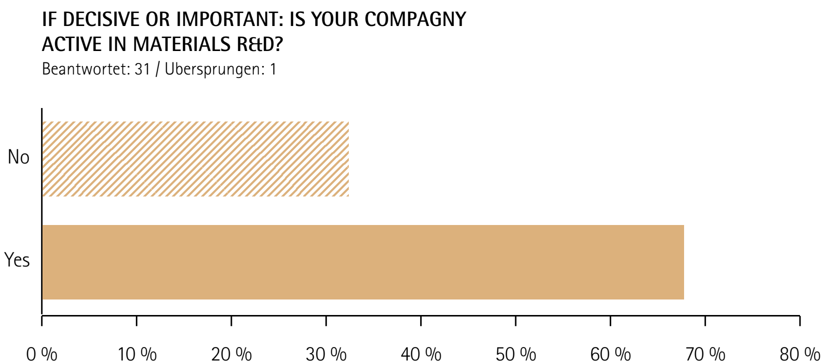
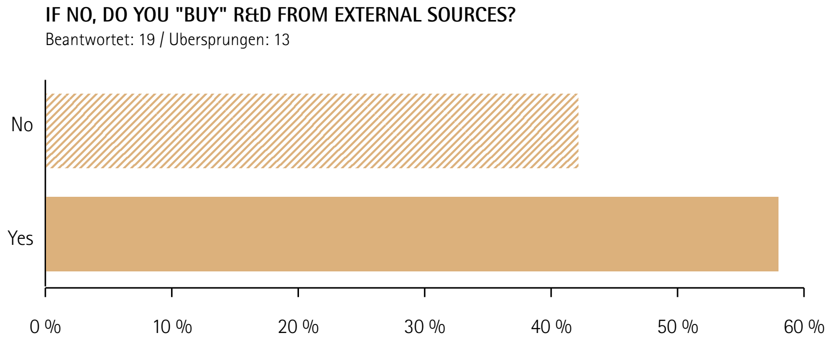


Figure 10:
Answers on question 4.



PARTICIPANTS

The 32 people who answered the questions represent a broad field of industrial sectors, which are dealing with metallic, ceramic, composite and polymeric materials mainly in the semi-finished products area but also in fields like finished products, formulation and processing and raw materials. In all of these companies materials play a decisive or important role which can be underlined by own R&D activity or R&D support from external sources. The main drivers for R&D in materials are cost savings followed by improved material properties and process technologies.

Having new product and technology innovations in mind and asked for the main needs in the development of new materials (question 6), see Figure 11, cost savings are mentioned first by 77.4 % of participants (answering persons 31), followed by new or improved material properties (71.0 %), new or improved process technologies (64.5 %), and quality improvement (58.1 %). The development is conducted in cooperation with R&D facilities (51.6 %) or with other companies (41.9 %).
Comparing the companies contacted in this survey with those contacted in the Netherland based on the scheme presented in Figure 12, we can show in Table 2 which is adapted to Switzerland, that we have to add Materials refiners and that producers for simple products, with relatively simple supply chain are not represented in the survey.

Figure 11 :
Answers on question 6.

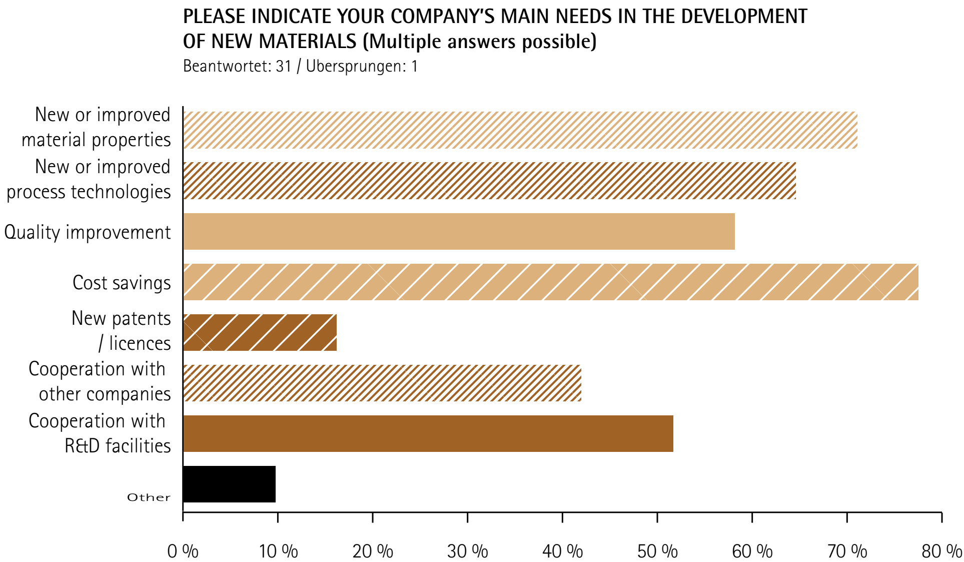


Figure 12 : **Schematic of chain of materials;** all categories of the companies are represented in this research (M2i, TNO). Source : (Bol and Bastein 2012, p 16).

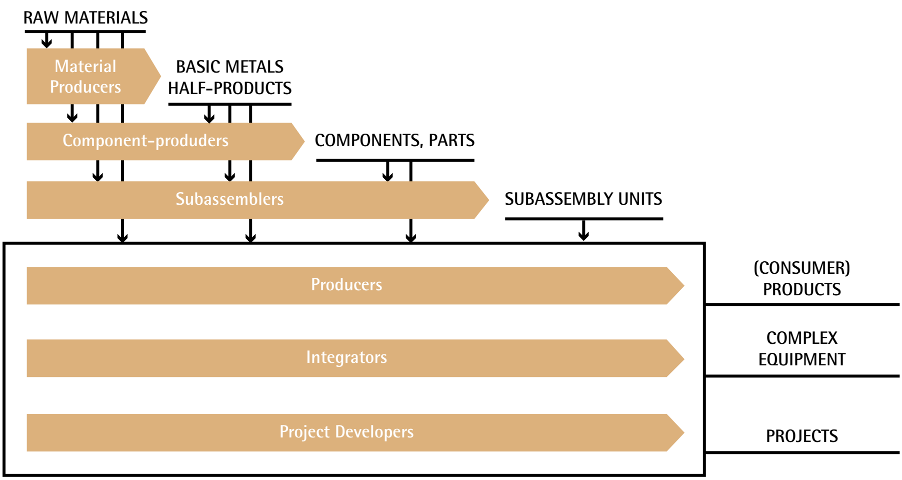


Table 2 : Description of the companies types in the materials value chain.

COMPANY TYPE	Description	Product example
MATERIAL PRODUCERS	Processing raw materials into (engineered) metals, basic metals and semi-finished products	Chemicals, doping materials and polymers
MATERIALS REFINERS	Processing materials and half products (components) and even end products to get specific functions / properties	Heat treatment, joining, layers & coatings
COMPONENT PRODUCERS	Producing components (mostly B2B market), using (engineered) metals, basic metals and intermediate goods	Materials and semi-finished products like e.g. screws and nails, stainless steel wire mesh
SUB-ASSEMBLERS	Producing subassemblies: more complex assemblies, no end products	Escalators, heating systems, power tools, electronic components
PRODUCERS	Producing relatively simple products, with relatively simple supply chain	
INTEGRATORS	Producing complex products and equipment (OEM), with a complex supply chain	Joint implants, dental surgical instruments, watch industry, mechatronics, high end steel radiators
PROJECT PRODUCERS	Development of processes and products based on customer specifications	Construction/architecture, sanitary application, waste water tubing systems

5.2 What criticality means and by what factors is it influenced

In the next part of the questionnaire, the question about criticality of materials (question 7, Figure 13) plays a major role. In the last years, the word "criticality" became a key word in many publications. However, publications also deal with other expressions, and therefore it is not so easy to keep track of the many activities and developments in the field. When asked for different expressions like material scarcity, material deficit, critical materials, critique materials, or supply insecurity, the answering contacted persons mentioned supply insecurity with 40 %, followed by critical materials (32 %); the other expressions were mentioned by 8 to 12 %.
A ranking from 1 (most probable cause) to 7 (least probable cause) was possible. In total 23 answers were given, and it is interesting that in some topics there is no favour for an option. Mining & processing and by this the question on future new capacity to get critical materials from

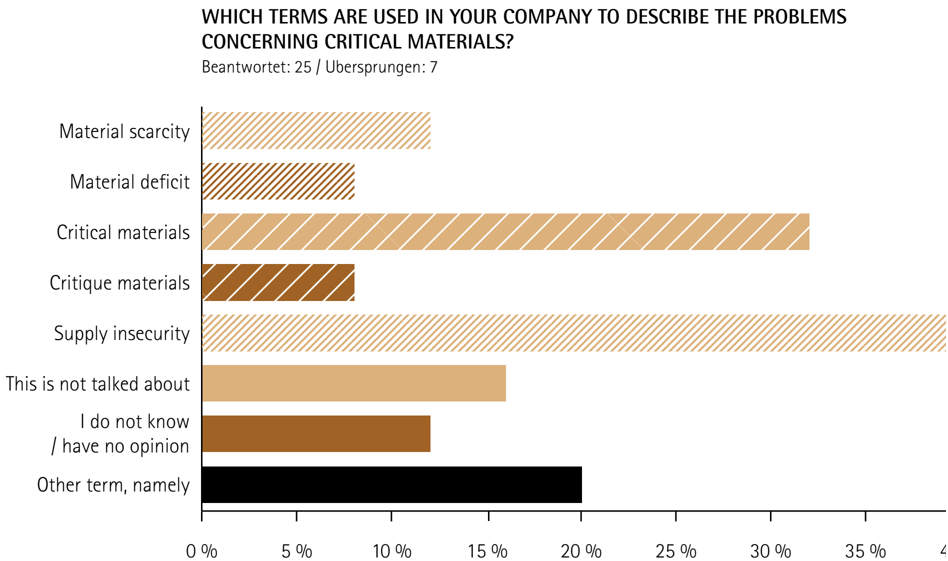
In question 8 (see Figure 14), we asked for factors which may have caused directly or indirectly materials criticality.

- **Economical factors.** Example : More demand than supply
- **Geopolitical factors**. Example : Limitation by export quota of producing countries
- **Suppliers**. Example : Suppliers monopoly on certain materials
- **Mining & processing.** Example : Not enough new capacity
- **Product design**. Example : Products are not design for reuse and recycling
- **Material sciences**. Example : Not enough research on alternative materials
- **Recycling**. Example : Not enough recycling of critical materials

primary sources was ranked as the less important factor in risk assessment followed by the geopolitical factors due to limitation by export quota of producing countries, which is seen as "dramatic" only by about 17 %, while 47 % of the answers do not see a cause for criticality (6-7/7). Product design (products are not design for reuse and recycling) and material sciences (not enough research on alternative materials) play more important roles (about 26 and 35 % in design and materials science respectively indicate 3/7, and 30 % indicate 1-2/7 for materials science) and recycling of critical materials is ranked in the middle of criticality (43 % mentioned 5-7/7 and only 26 % mentioned 2/7). It is interesting that Materials science is ranked as being ofhigher importance than recycling and product design as it may stronger influence in the long term risk assessment of companies. The economical factors and the suppliers are the most important factors in the ranking table. Especially suppliers and the possible suppliers monopoly on certain materials (9 answers = 40 % at 2/7) are seen as a strong cause for criticality.

In this questions some people gave additional answers like "development without thinking in a circle, how much do we need, how much do we have" and mentioned the regulation (REACH, Cr(VI)) issue, which may cause also criticality.

Figure 13 : **Answers on question 7.**

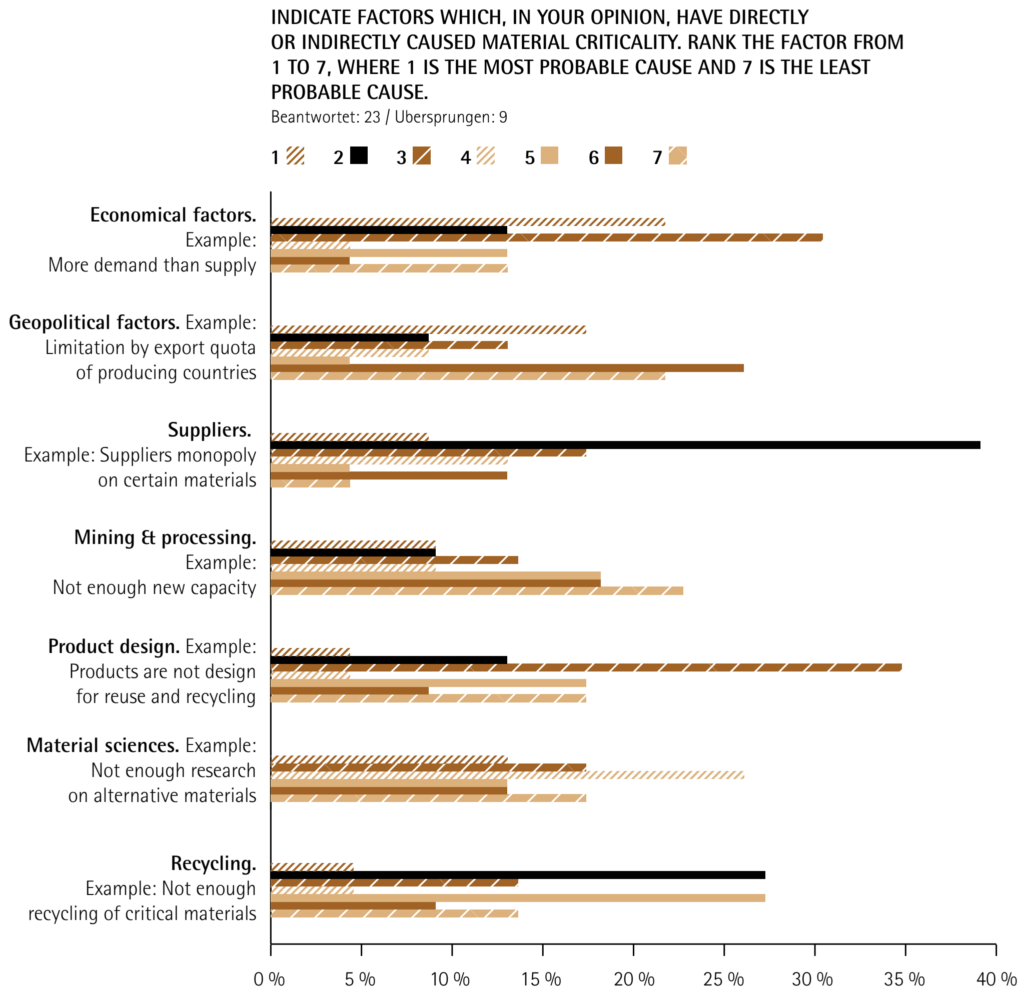


Based on the answers a ranking regarding the (relative) importance was prepared (Table 1) :

Table 3 : Ranking of factors on the importance of materials criticality.

FACTOR	Total points	Ranking
SUPPLIERS	74	1
ECONOMICAL FACTORS	78	2
MATERIAL SCIENCES	80	3
RECYCLING	89	4
PRODUCT DESIGN	95	5
GEOPOLITICAL FACTORS	101	6
MINING & PROCESSING	102	7

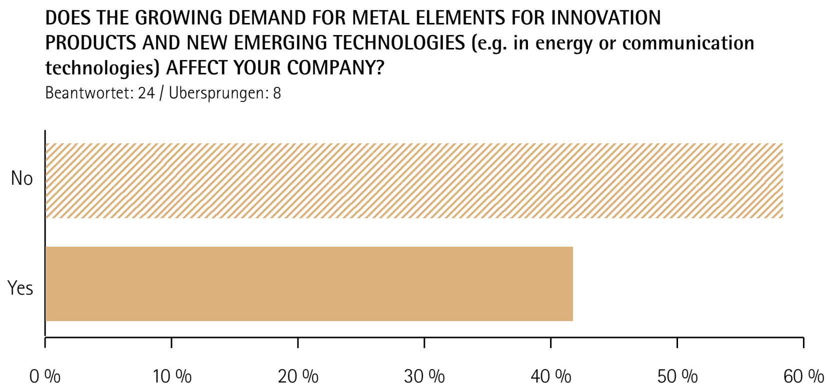
Figure 14 : Answers on question 8.



5.3 Influences of criticality in industry

As already mentioned, the demand for new and advanced technologies in the industrial and emerging countries especially in the field of communication, new energies and transportation leads to a higher need of specific elements, also and especially in the group of critical elements. Therefore we asked in question 9 if the growing demand for metal elements for innovative products and new emerging technologies affect the companies contacted in the survey. We received 24 answers from which 41.7 % (10 answers) confirmed this, while 58.3 % (14 answers) see no effect on their company. Some specific answers were given mentioning that special elements for innovative products may have higher prices or show price variations (metal surcharge) and that in fact the increase of materials prices affect the prices of components, e.g. for catalysts or magnets. Those companies which are active in materials processing receive semi-finished products and are not influenced as they deliver refinement which is an added value independent on the material. It could have an influence if the materials properties change because of the use of other elements – e.g. the use of lead in aluminium and brass alloys - has been drastically reduced because of growing environmental concerns which will be compensated by other elements. However, further research and development were necessary to get similar effects in machinability such as in alloys with lead. Therefore the REACH Regulation of the European Parliament (Registration, Evaluation, Authorisation and Restriction of Chemicals) is often a very important issue in com-

Figure 15: Answers on question 9.



panies to manage the risks from chemicals and to provide safety information on the substances. Being in a supply and production chain requires information on the properties of their chemical substances, to allow their safe handling and by this to find suitable alternatives for elements or substances.
For critical materials as well as for possible toxic materials it would be of interest to have accordant experts in the company. So we asked in question 10 how and by whom developments in view of critical materials are followed in Swiss companies. 19 people answered the questions and showed that a variety of different solutions were chosen from "no people" to "a group of 12 people are working in this field", depending on the size of the company as well as on the need to document. The other information sources can be summarized as follows:

SOURCES OF INFORMATION ABOUT CRITICAL MATERIALS

The exchange with suppliers is the main source to be informed about critical materials. The contact to suppliers and other experts is mostly fostered by technology & innovation departments, quality and research department and by specific commissions or regulatory affairs officer as well are may be in charge for this exchange. Sources for information are also conferences, literature, or networking contacts. In any case it is necessary to find alternatives if critical products are discovered; this is part of the core business of a company.

CASE FROM PRAXIS: REPLACEMENT OF A METAL OXIDE

In an interview, a case of a product was mentioned which was based on a very specific function of a metal-oxide. As the material price was very volatile and increased steadily, the company decided to start a development to replace the metal-oxide based component by another synthetic one based on polymers. The development which took about 2 years was finally successful and the price of the new material was only slightly higher than that of the metal-oxide based product. However, the metal-oxide price decreased in the meantime and therefore the polymer development was put aside.

If criticality is discovered, what measures are taken by a company to react (question 11, Figure 16)?

Figure 16:
Answers on question 11.

Out of 22 responses, 11 said that no measures are taken and 11 indicate measures summarized as following:

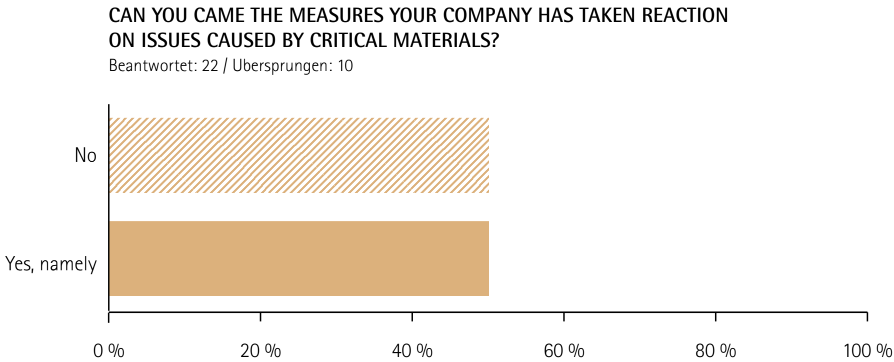


Figure 17 :
Answers on question 12.

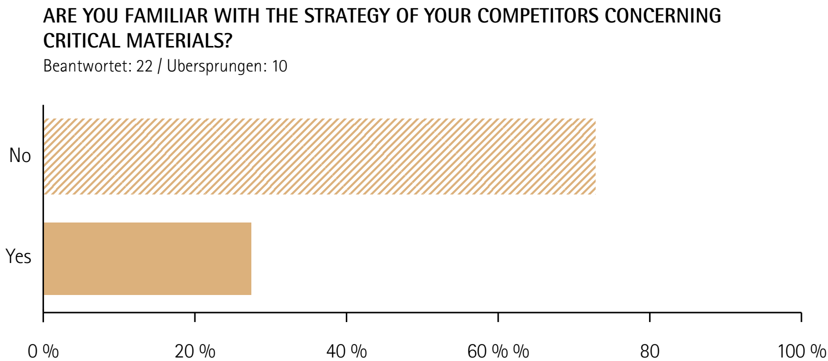
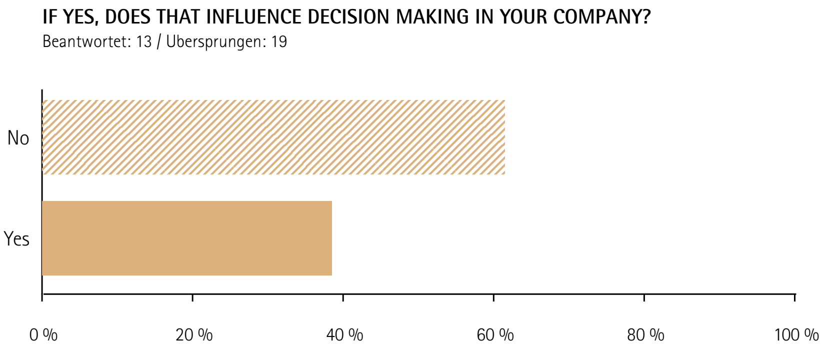


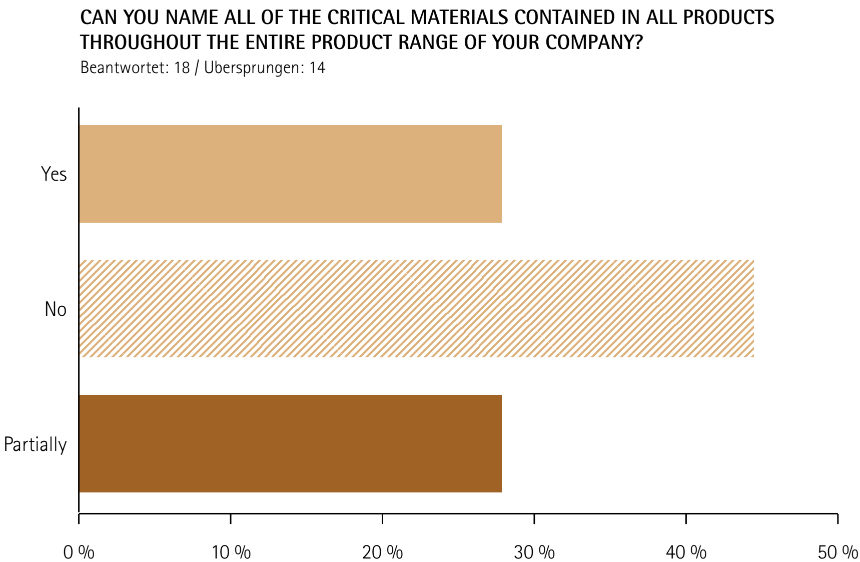
Figure 18 :
Answers on question 13.



Measures to react on criticality
Companies may calculate more reserve stocks, relocate some of the materials or are looking for alternative suppliers in a very early stage. Sales-forecasting and frame agreement with suppliers certifications (incl. supply chain policy) cooperation's is one measure which can be taken. It is furthermore important to avoid influence on innovative products and maintain high efforts for quality control. Alternatives are e.g. evaluated for Cr(VI). In some cases it may even come to geographical repositioning & alternative solution in R&D in order to reduce the amount of critical elements or to develop new materials with less critical elements.

In question 12 (Figure 17) about the knowledge companies may have about competitor's strategies in critical elements, 16 of 22 answers indicated that they do not know about such strategies, and from 6 answers with yes it was indicated that not much is done yet and if so, then it is a short term strategy which dœs not correlate with the long term impact which critical materials may have on the products and by this on the economy. For those companies who are aware of competitor's strategies there is an influence on the decision-making in their own company realized by 38.5% of the participants' companies and not realized by 61.5% (in total 13 answers in question 13, see Figure 18). This answer to question 13 is in agreement with the answer to the question how well developments in the field of material criticality are followed within their own company (question 14, Figure 19). These developments are followed from "not at all" to "very closely", so that no common trend can be derived.

Figure 19 :
Answers on question 14.



5.4 Critical elements in the company

From participants, only 18 answered on the question about the knowledge of critical elements in the product range of the company (question 15). 27.8 % indicated that they know these elements, 27.8 % indicated that they know the elements partially, and 44.4 % did not know the elements. The product groups for which possible critical elements were highlighted (question 16) are:

SPECIFIED PRODUCT GROUPS CONTAINING CRITICAL ELEMENTS
High temperature supports, ceramic fuel cells (SOFC), thermal barrier coatings, ring spinning machine, electronic components, counterweight and oven and various materials were mentioned such as Kayem alloys (based on Zn with about 3.9 - 4.3 wt % of Al, 1.8 - 3.5 wt % of Cu, 0.09 – 2.2wt % of Mg, and each ≤ 0.003 wt % Pb, Cd and Sn, ≤ 0.030 Fe, rare earth elements, Nb contained in several materials, vacuum brazing alloys and gold.)

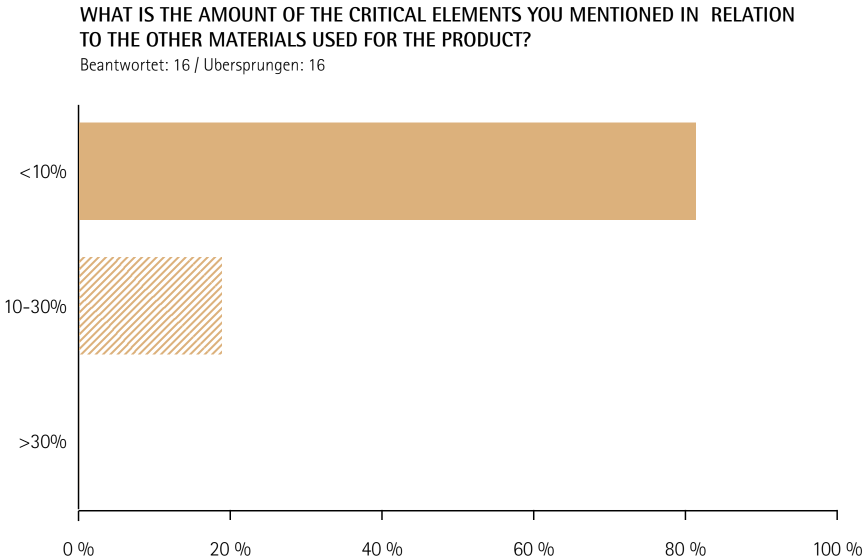
The next question listed various elements from the list of critical elements and people were asked to list those elements which are in the products of the company. The mostly mentioned elements are:

CRITICAL ELEMENTS USED IN COMPANIES' PRODUCT GROUPS
- Indium (in), magnesium (mg) and lanthanum (la): 25 % of answers
- Cobalt (co), graphite (c), molybdenum (mo), niobium (nb), yttrium (y) and cerium (ce): 18.8 %
- Tungsten (w), platinum (pt), ruthenium (ru), dysprosium (dy), europium (eu), gadolinium (gd), erbium (er): 12.5 %
- Others: gallium (ga), germanium (ge), tantalum (ta), iridium (ir), palladium (pd), rhodium (rh), neodymium (nd), scandium (sc), praseodymium (pr), holmium (ho), lutetium (lu).

The relation between the products and materials was also investigated (question 16 and 17).

CRITICAL ELEMENTS AND THEIR USE IN PRODUCTS
- Indium: plastics, vacuum brazing alloys,
- Magnesium: thermal barrier coatings, gold alloys: rare earth elements
- Lanthanum: ceramic fuel cells (SOFC), thermal barrier coatings
- Cobalt: oven
- Graphite: high temperature supports, ring spinning machine
- Cerium: ceramic fuel cells (SOFC), thermal barrier coatings

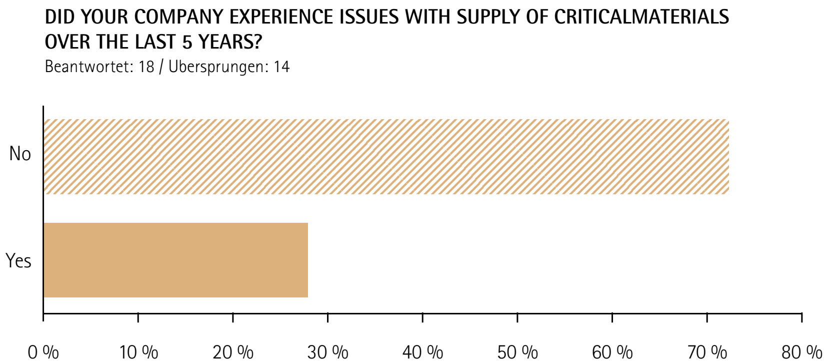
Figure 20:
Answers on question 15.



In most of these applications, REE play also an important role. Various suppliers were mentioned in question 18 for such materials like e.g. SGL Carbon (Graphite), Pemco and Ferro as enamel suppliers for cobalt, DKSH – BIBUS (Titanium for Medical Devices); others named no specific company.
The critical elements mentioned by the various companies are used only in small quantities related to other materials used for components or final products. Fifty per cent of the participating people answered this question and the following (question 19 and 20) regarding the value of the elements in view of the overall value of the project. The amount of critical elements in a product is estimated by 81.3% to be less than 10%, the rest estimates the amount to 10 to 30%. The value of the critical elements in a final product are similarly estimated to be less than 10% by 68.8% and around 10 to 30% by 25% of participants. As prices of such critical elements were volatile in the last years, mostly increasing and by this potentially influencing the price of a product or even the market, it was asked about the price volatility of the mentioned critical materials the last 5 years (question 21) and the use of these materials –

increasing or decreasing (question 22). Not many answers were received (only 9 from 32) and the materials mentioned were (2 times) cerium, lanthanum, magnesium, platinum, and tungsten, and one time each gadolinium, germanium, graphite, holmium, iridium, lutetium, molybdenum, palladium, and yttrium as being volatile in price. For many of these materials there is a tendency for increasing use. This in-/decrease was specified in question 23. The answers indicated that the use will increase "because of increasing production numbers" and increase also "due to more products with electronic components" or in case of palladium "due to hydrogen membranes as a new product". However, also a decrease in their use is possible, e.g. "due to R&D activities to substitute critical elements within brazing alloys". Another option for the decrease may be more "regulations which prohibit certain elements" which are a higher "limiting factor at the moment" than the "insufficient supply" as in some cases the components which contain such materials are bought by suppliers, and not the materials themselves. Exotic materials like e.g. Kayem alloys are used in very small consumption (< 100 t / year, i.e. 1 t Mg / year) and may increase slightly. Finally an in-/ or decrease may be related to the consumer's behaviour and the demand for certain products that request such critical materials.
It is clear that critical materials may affect companies due

Figure 21: **Answers on question 24.**



to supply hurdles, volatility in prices or even by changing quality, by questions of regulations, and certifications from the country of origin that the raw material's origin is not in regions where the extraction may support warfare (Dodd-Frank Act 1502 for conflict minerals).
Materials criticality is so important that it may affect the risk management management. Being asked about this, 62 % of participants (question 25 with totally 18 answers, see Figure 22) indicated that critical materials are not involved in the risk management of the company, 27.8 % stated that this is an active part of the management, and 11.1 % see this topic to be included in risk management in the future. To minimize risks, various options were proposed as measures in question 26, which was answered by 18 people. Most of them answered to spread the risks by using multiple suppliers (56 %), while many also see a more efficient use of the materials and substitution as valuable possibilities (44 % each). Stock piling critical materials to meet possible supply disruptions were chosen by 22 %.

Figure 22:
Answers on question 25.

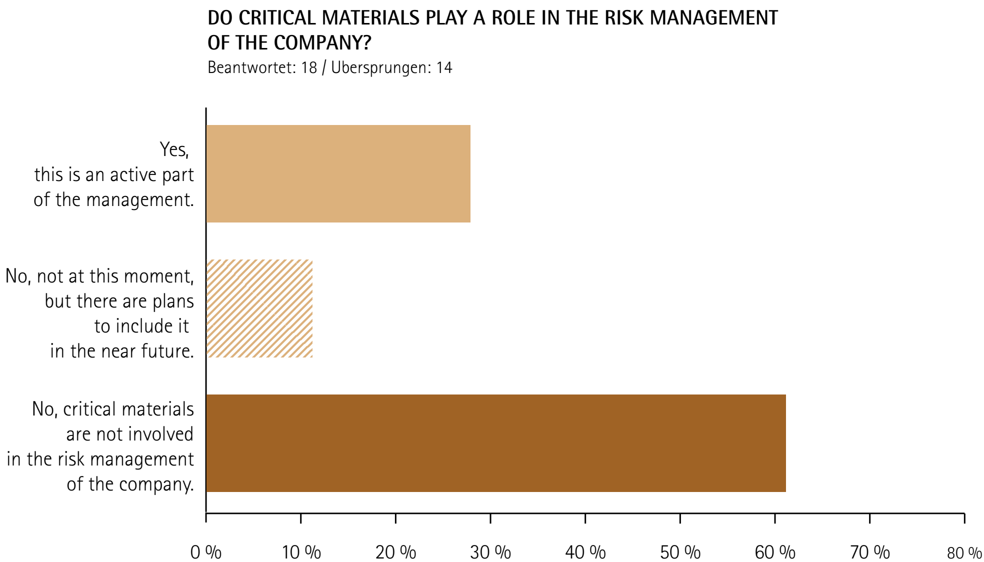


Figure 23:
Answers on question 26.

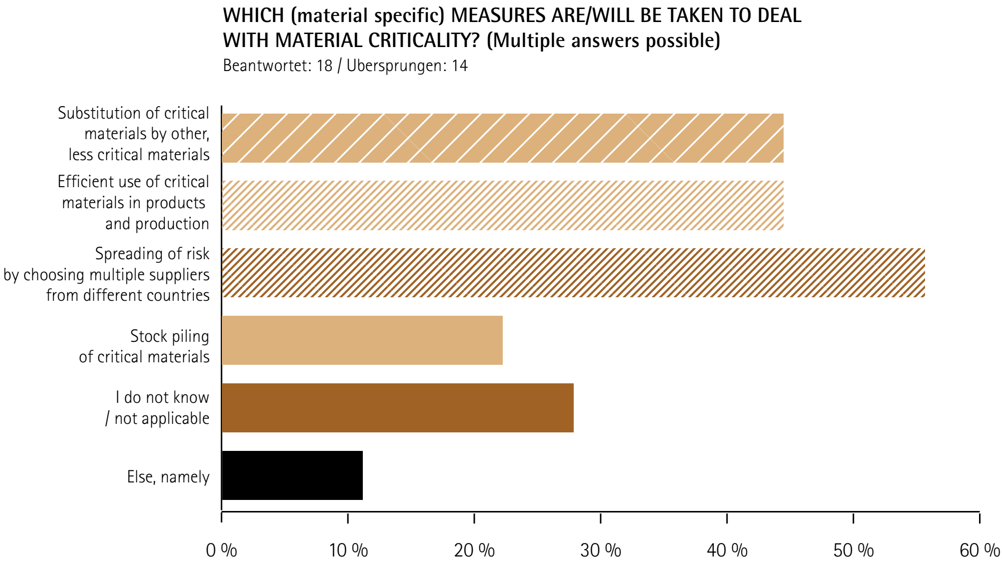
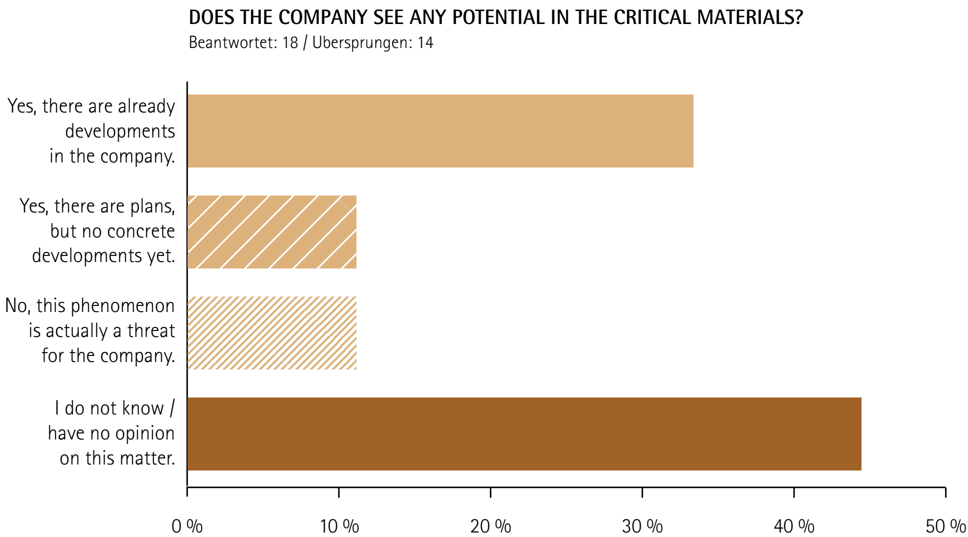


Figure 24:
Answers on question 29.



HOW PROBLEMATIC IS THE CRITICAL MATERIALS ISSUE FOR COMPANIES ?

Various suggestions were given for avoiding problems with availability. Some companies or their suppliers have such materials on stock for min. 6 months or they would use alternative materials, others see this question not as relevant or propose to enhance R&D efforts. About 40 % of the 15 answers on question 28 regard critical materials as serious problem, but due to the timely reaction of the company they expect to be able to deal with possible limitations appropriate for themselves. 26.7 % do not see upcoming problems posed by critical materials, and 20 % even think that "Critical materials have never been a problem." Only 13 % think that "Critical materials are a much bigger problem and limit the production of certain components and or products."

Regarding the potential of critical materials for the company (question 29), 44.4 % of participants have no opinion or do not know about this issue, while 33.3 % of the answering persons indicate that there is already a development in the company, 11 % each see it either as threat or have no concrete plans. Companies may not like to enter into discussions which rely to propriety issues.
Support for a company could origin in different approaches which could be chosen in question 30.

WHAT COULD SUPPORT COMPANIES IN HANDLING CRITICAL MATERIALS ?

50 % of 18 participants see the use of databases covering data and development of critical materials as a possible tool to meet the problems posed by critical materials, followed by the suggestions to have more insight in the quantities of critical materials in all products of the company and the personnel training in this field to gain more knowledge. Neither experts to hire nor swift expert checks of the company is widely seen as a solution to the issue (only 1 answer each). Regular meetings may be of interest (3 answers). Regarding the content of a database (question 31, Figure 26), 15 out of 18 answers (multiple choice) mentioned regulatory issues regarding critical elements followed by their properties, economic and financial evolution.

Figure 25: Answers on question 30.

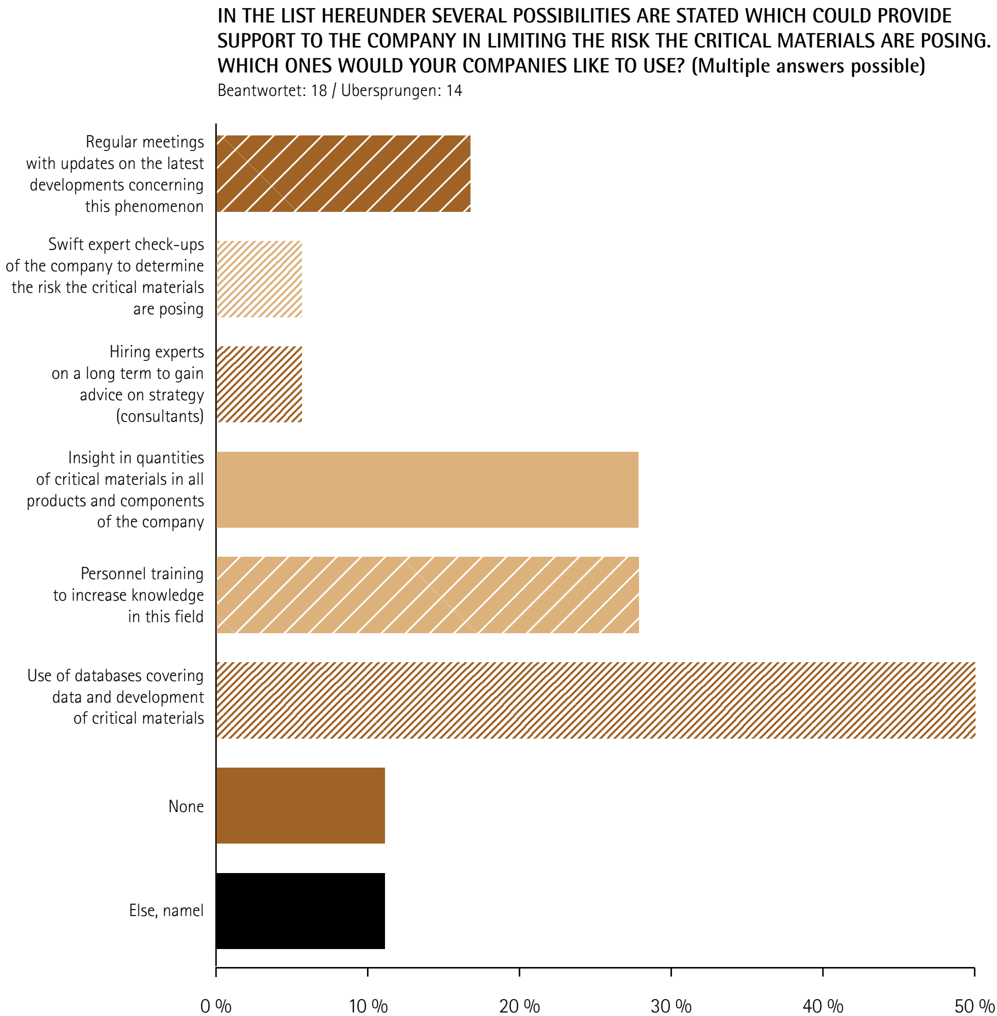
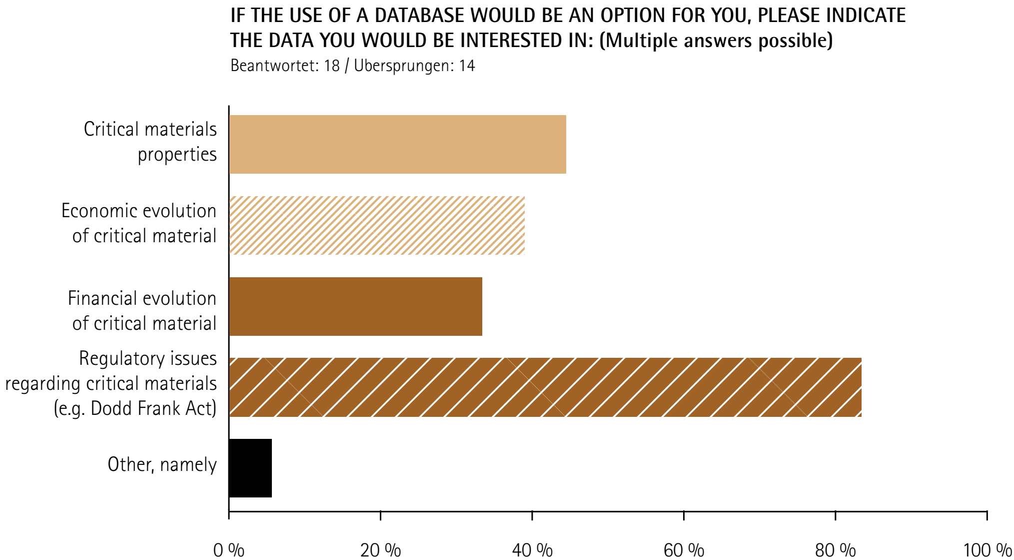


Figure 26:
Answers on question 31.



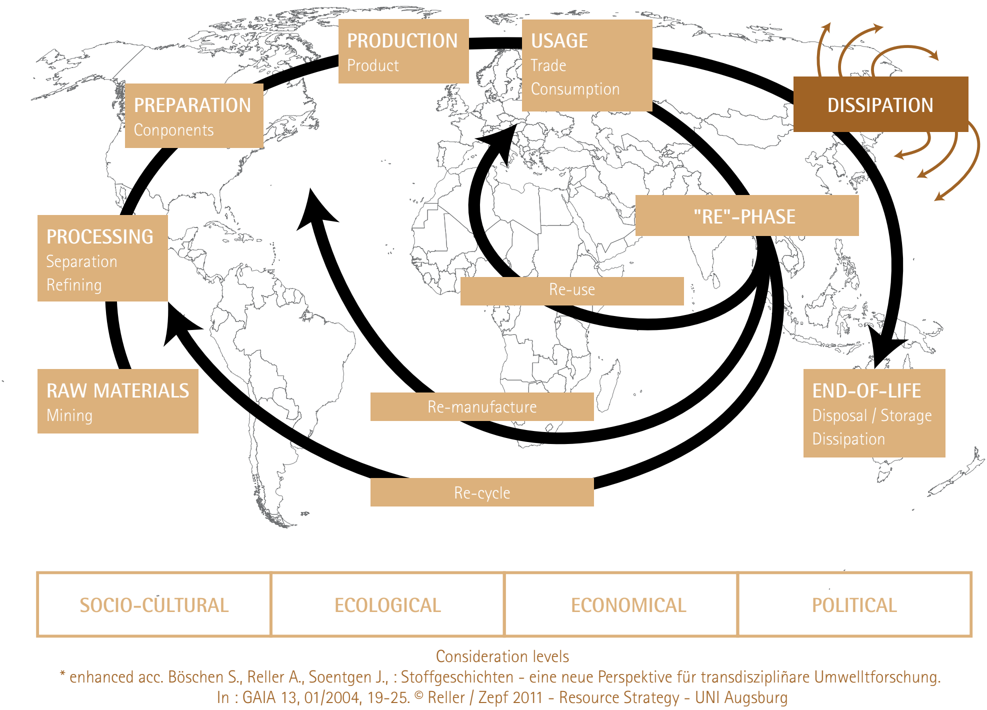
6. DISCUSSION AND RECOMMENDATIONS

For companies answering the questionnaire, criticality is related to supply insecurity of the materials they need. The economical factors which rely to the increased demand for critical elements are more pronounced than geopolitical factors caused by export quota of producing countries, although these two factors are strongly related with each other also because the suppliers needed are part of this chain in the criticality of raw materials. However, companies do not agree on the effects of economical factors on new emerging technologies in their fields, and half of them notice an effect from a higher demand of certain materials on the own production. Considering the wide spectrum of materials processing companies which were asked in this survey and the various levels they cover in the value chain from consumer products and medical device companies, watch companies to those who process components to achieve specific properties and functions (heat treatment, joining, layers & coatings), the gap in the answers is understandable. In some cases higher prices or price variations (metal surcharge) may lead to an increase of materials prices and by this affect the prices of components, e.g. for those companies dealing with catalysts or magnets. The exchange with suppliers is the main source to be informed about critical materials and the departments in the companies dealing with technology & innovation, quality and research or regulatory affairs are in charge to exchange with suppliers. Companies use all other sources of information, their networks with clients and scientists to be informed so to find alternatives if critical products are discovered and substitutes or new technologies would be necessary. The case study of a metal oxide substitution has shown the problems with substitution of elements or materials. The decision for a development of new materials, changes or adaptation in the processing or in case that no substitute is available, the creation of new process technologies or even other ways to achieve the desired function has to be taken long before the situation becomes critical. Materials science and engineering is still a long-term investment, and smaller companies may even not afford to pay for such an investment.

It is therefore important to start very early to be informed about activities in the development of materials, and it seems that not enough research projects and activities in the field of alternative materials are ongoing and that e.g. product design is not part of such projects. Many products today are not designed for reuse and recycling, however companies see both issues – materials development and design of materials and components – directly related to the production and processing steps of their products. These aspects are therefore important to take into account when discussing criticality. On the other hand, recycling seems not to be such an important point in the debate on criticality as it is outside the value chains the companies are related to. The terms and implications of a "whole life cycle approach" or a "circular economy" may not be yet a point of discussion in the companies, and the linear way of creation, use and disposal is still more pronounced. Collection and recycling or re-use of materials and components, so-called "urban mining", may lead to a reduction in the use of external primary resources and even to a new business in countries which are poor in resources.

A. Reller et al. have worked on the "Stuff Approach" depicting a cyclic supply chain instead of a linear one. This approach requires in-depth knowledge of all kinds of factors covering use, mining, but also social, economical and environmental issues as well as recycling opportunities and data about materials dissipation. To gather such data and thus being able to make valid statements or even predictions about supply security and price development of critical materials, this data has to be gathered and aggregated. Thus, a data network as regarded as a valid option by many of the participant would be a project that could be interesting for Swiss industry, research and also the service sector. Better education, training and overview of a company's use of critical metals could also help industry to be more informed about the materials they are using and thus enabled to take informed long-term decisions.

Figure 26: **Story of Stuff Approach according to Armin Reller and Volker Zepf,** University of Augsburg (2011).



In summary, our survey shows that critical materials are at the moment not the most burning issue for Swiss producing companies, but have a certain priority and are expected to gain a growing relevance in the future. Our recommendations for the Swiss industry cover therefore a) the provision of training and education in risk factors of critical materials and ways to mitigate them for decision-makers in their companies, b) to stay closely informed about developments in the field, especially concerning Switzerland, and foster networking with experts in the area and companies facing these problems, and c) to use information systems informing about critical materials developments.
At the ESM Session at the World Resources Forum 2016 in Davos, some of the topics of this report were discussed (see http ://www.esmfoundation.org/event/davos-2015/). One of the invited speakers, Willem Bulthuis, active as a Business Angel and Digitization Advisor, presented and discussed how to mobilize industry to act on material criticality and proposed concrete actions to make "material criticality" an integral part of corporate Risk Management of industrial companies. It is suggested to make all stakeholders in a company aware of materials criticality and to reduce the dependency on critical materials in the long term.

7. ANNEX : QUESTIONS WITH ANSWERS

7.1 What are the 5 main products provided by your company?

NUMBER	1	2	3	4	5
1	Brass (CuZn)	Stainless steel (X8CrNiS 18-9)	Plastic (PC, PPO, PPS, ABS)	Hard Metal (V714)	Magnets (SmCo)
2	PVC-Blister films	Antimicrobial surfaces			
3	Filter mesh	Screen Printing mesh	Process filtration	Architecture fabrics	Industrial fabrics for mining and refining
4	AlTiN	AlCrN	TiSiN	Al2O3	TiCN
5	Hip joint implants	Knee joint implants	Shoulder joint implants	Bone replacement	ACL healing implants
6	Precious metal layers	Molded Interconnect Devices	Finishing of electronic components		Finishing of medical components

NUMBER	1	2	3	4	5
7	Fuel cell based heaters				
8	Aluminium	Silanes	Nanopowder (several)		
9	Tungsten carbide	Zirconium oxide	Polyester aluminium composites	Nickel-Graphite composite	Aluminium oxide
10	Powertools	Anchors	Screws and Nails	Fire stop	Drill bits / diamond tools
11	Zinc alloys	Al alloys			
12	Sanitary systems (cisterns, flushing devices, traps..)	Drinking water distribution systems (inside building)	Waste water tubing systems (rain- + sewage water)		
13	Watches				
14	Stainless steel wire mesh AISI 304	Stainless steel wire mesh AISI 316	Stainless steel wire mesh Nickel 200		
15	Textile machinery	Textile components			
16	Oven/steamer	Hob	Washing machine	Laundry dryer	Dishwasher
17	Basic chemicals	Chemical Intermediates	Plastics	Formulations	Agrochemicals
18	Iron castings	Aluminium castings	Magnesium castings		
19	TiO2 with various dopings	LiNbO3	V2Ox	Al2O3	ZnO
20	ECTFE	PFA	ETFE	PVDF	PTFE
21	Lifts	Escalators	Maintenance Services for Lifts & Escalators		
22	Heat treatment - surface hardening by induction	Heat treatment - gas nitriding	Heat treatment - vacuum hardening	Heat treatment - case hardening	
23	Brazing in vacuum and protective gas atmosphere	Heat treatment in vacuum and protective gas atmosphere	Electron beam welding	Thermal spraying	sintering of MIM components
24	High end steel Radiators	Innovative plastics radiators	Heta pumps combined with heat recovery units	Immersion heaters for bathroom radiators	
25	Dental implants	Dental restorative components	Dental surgical instruments		
26	Medical devices	Mechatronics	Nuclear	General machine industry	Telecom
27	Testing services				
28	Semi-finished products in precious metals	Semi-finished products in stainless steel	Semi-finished products in titanium and special alloys	Semi-finished products for medical devices	Tooling based on cemented carbide
29	Coatings				

7.2 What role do materials play in your company?

ANSWER OPTIONS	Response Percentage	Response Count
DECISIVE	67.7 %	21
IMPORTANT	32.3 %	10
MINOR	0.0 %	0
NEGLIGIBLE	0.0 %	0
ANSWERED QUESTION	31	
SKIPPED QUESTION	1	

7.3 If decisive or important: is your company active in materials R&D?

ANSWER OPTIONS	Response Percentage	Response Count
YES	67.7 %	21
NO	32.3 %	10
ANSWERED QUESTION	31	
SKIPPED QUESTION	1	

7.4 If no, do you "buy" R&D from external sources?

ANSWER OPTIONS	Response Percentage	Response Count
YES	57.9 %	11
NO	42.1 %	8
ANSWERED QUESTION	19	
SKIPPED QUESTION	13	

7.5 At which stage of a product cycle is your company active in materials? (Multiple answers possible)

ANSWER OPTIONS	Response Percentage	Response Count
RAW MATERIALS	45.2 %	14
FORMULATION / PROCESSING	64.5 %	20
SEMI-PRODUCTS	80.6 %	25
FINISHED PRODUCTS	71.0 %	22
APPLICATION	54.8 %	17
ANSWERED QUESTION	31	
SKIPPED QUESTION	1	

7.6 Please indicate your company's main needs in the development of new materials? (Multiple answers possible)

ANSWER OPTIONS	Response Percentage	Response Count
NEW OR IMPROVED MATERIAL PROPERTIES	71.0 %	22
NEW OR IMPROVED PROCESS TECHNOLOGIES	64.5 %	20
QUALITY IMPROVEMENT	58.1 %	18
COST SAVINGS	77.4 %	24
NEW PATENTS/LICENCES	16.1 %	5
COOPERATION WITH OTHER COMPANIES	41.9 %	13
COOPERATION WITH R&D FACILITIES	51.6 %	16
OTHER	9.7 %	3
ANSWERED QUESTION	31	
SKIPPED QUESTION	1	

7.7 Which terms are used in your company to describe the problems concerning critical materials?

ANSWER OPTIONS	Response Percentage	Response Count
MATERIAL SCARCITY	12.0 %	3
MATERIAL DEFICIT	8.0 %	2
CRITICAL MATERIALS	32.0 %	8
CRITIQUE MATERIALS	8.0 %	2
SUPPLY INSECURITY	40 %	10
THIS IS NOT TALKED ABOUT	16 %	4
I DO NOT KNOW/ HAVE NO OPINION	12.0 %	3
OTHER TERM, NAMELY	20.0 %	5
ANSWERED QUESTION	25	
SKIPPED QUESTION	7	

7.8 Indicate factors which, in your opinion, have directly or indirectly caused material criticality. Rank the factor from 1 to 7, where 1 is the most probable cause and 7 is the least probable cause.

ANSWER OPTIONS	1	2	3	4	5	6	7	Response Count
Economical factors Example : More demand than supply	5	3	7	1	3	1	3	23
Geopolitical factors Example : Limitation by export quota of producing countries	4	2	3	2	1	6	5	23
Suppliers Example : Suppliers monopoly on certain materials	2	9	4	3	1	3	1	23
Mining & processing Example : Not enough new capacity	2	2	4	2	4	4	5	22
Product design Example : Products are not design for reuse and recycling	1	3	8	1	4	2	4	23
Material sciences Example : Not enough research on alternative materials	3	4	6	3	3	4	0	23
Recycling Example : Not enough recycling of critical materials	1	6	3	1	6	2	3	22

ANSWER OPTIONS	Question Totals
Other, namely : – development without thinking in a circle, how much do we need, how much do we have – regulation (REACH, Cr(VI) issue)	2
ANSWERED QUESTION	23
SKIPPED QUESTION	9

7.9 Dœs the growing demand for metal elements for innovative products and new emerging technologies (e.g. in energy or communication technologies) affect your company?

ANSWER OPTIONS	Response Percentage	Response Count
YES	41.7 %	10
NO	58.3 %	14
ANSWER OPTIONS		Question Totals
Specification/Comment: – High prices – Price variations for numerous metals are considered by an metal surcharge which is based on trade indexes. – Low indirect effect (mostly in electronics) the components including these materials become more expensive – Catalysts, growing demand on rear earth metals for magnets influences availability and prize – My company is mainly involved in developping alternative eco-sustainable materials. – We are active in materials processing which means that semi-finished products are supplied to us for refinement. Actually REACH has a stronger impact on material usage. – R & D contracts		9
ANSWERED QUESTION	24	
SKIPPED QUESTION	8	

7.10 How (and by whom) are the developments in view of materials criticality followed within your company?

ANSWER OPTIONS	Response Count
ANSWERED QUESTION	19
SKIPPED QUESTION	13

ANSWER OPTIONS	Response Count
— No one — Exchange with suppliers by head of R&D — Supply teams, experts — Technology & innovation department — Specific commission — External — Mosty by our suppliers — Business services and procurement — To find alternatives — This is the core business of the company. — By myself. We are exposed to the raw material suppliers. — Lead offices — Quality and r&d departments by conferences, literature, network contacts — We define critical products and suppliers and are looking for alternative suppliers in a very early stage. Done by quality and general management. — Group technology — In the majority of cases customer driven an realization by supply chain — Researchers (mat'ls engineers) — Regulatory affairs officer A group of 12 persons are working in this field	

7.11 Can you name the measurements your company has taken as reaction on issues caused by critical materials?

ANSWER OPTIONS	Response Percentage	Response Count
NO	50 %	11
YES, NAMELY : – Calculate more reserve stocks – Relocation, material hedging, innovative products not introduced, high efforts for quality control – Evaluate alternatives to Cr(VI) – Stock – Geographical repositioning & alternative solution R&D – Investigations to be able to reduce the amount of critical elements – Develop new materials with less critical elements. – We define critical products and suppliers and are looking for alternative suppliers in a very early stage. Done by quality and general management. – Sales-Forecasting and frame agreement with suppliersw – Certifications (incl. supply chain Policy) cooperations – A group of 12 persons are working in this field	50 %	11
ANSWERED QUESTION	22	
SKIPPED QUESTION	10	

7.12 Are you familiar with the strategy of your competitors concerning critical materials?

ANSWER OPTIONS	Response Percentage	Response Count
YES	27,3 %	6
NO	72,7 %	16
ANSWER OPTIONS		Question Totals
Specification/Comment: – Partially we are – Not much is done. Most of the strategy is short term, while critical materials will have an impact in the medium long term.		2
ANSWERED QUESTION	22	
SKIPPED QUESTION	10	

7.13 If yes, dœs that influence decision making in your company?

ANSWER OPTIONS	Response Percentage	Response Count
YES	38,5 %	5
NO	61,5 %	8
ANSWER OPTIONS		Question Totals
Specification/Comment		0
ANSWERED QUESTION	13	
SKIPPED QUESTION	19	

7.14 Indicate on the scale given below how well developments in the field of material criticality are followed within your company.

ANSWER OPTIONS	Not at All 1	2	3	4	5	6	7	8	9	Very Closely 10	Rating Average	Response Count
Developments in the field of material criticality are followed within my company...	2	4	2	2	2	2	0	4	3	1	5.23	22
ANSWERED QUESTION	22											
SKIPPED QUESTION	10											

7.15 Can you name all of the critical materials contained in all products throughout entire product range of your company?

ANSWER OPTIONS	Response Percentage	Response Count
YES	27,8 %	5
NO	44,4 %	8
PARTIALLY	27,8 %	5
ANSWERED QUESTION	18	
SKIPPED QUESTION	14	

7.16 Please chose a relevant product group as an example to answer the next question.

— High temperature supports
— Ceramic fuel cells (sofc)
— Thermal barrier coatings
— Kayem alloys
— Electronic components
— Ring spinning machine
— Oven
— Plastics
— Rare earth elements
— Nb is contained in several materials and this element is quite scarce.
— Counterweight
— Vacuum brazing alloys
— Rohmaterial
— We have no own products - know from analysis :
— Gold alloys
— Rare earth elements

7.17 Which element(s) listed hereunder are used in the chosen product group? (Multiple answers possible)

ANSWER OPTIONS	Response Percentage	Response Count
ANTIMONY (Sb)	0.0 %	0
BERYLLIUM (Be)	0.0 %	0
COBALT (Co)	18,8 %	3
FLUORSPAR	0.0 %	0
GALLIUM (Ga)	6.3 %	1
GERMANIUM (Ge)	6.3 %	1
GRAPHITE (C)	18,8 %	3
INDIUM (In)	25.0 %	4
MAGNESIUM (Mg)	25.0 %	4
MOLYBDENUM (Mo)	18.8 %	3
NIOBIUM (Nb)	18.8 %	3
TANTALUM (Ta)	6.3 %	1
TUNGSTEN (W)	12.5 %	2
PLATINUM (Pt)	12.5 %	2
IRIDIUM (Ir)	6.3 %	1
OSMIUM (Os)	0.0 %	0
PALLADIUM (Pd)	6.3 %	1
RUTHENIUM (Ru)	12.5 %	2
RHODIUM (Rh)	6.3 %	1
YTTRIUM (Y)	18.8 %	3
NEODYMIUM (Nd)	6.3 %	1
CERIUM (Ce)	18.8 %	3
LANTHANUM (La)	25.0 %	4
SCANDIUM (Sc)	6.3 %	1
DYSPROSIUM (Dy)	12.5 %	2
SAMARIUM (Sm)	0.0 %	0
TERBIUM (Tb)	0.0 %	0
PRASEODYMIUM (Pr)	6.3 %	1
PROMETHIUM (Pm)	0.0 %	0
EUROPIUM (Eu)	12.5 %	2

ANSWER OPTIONS	Response Percentage	Response Count
GADOLINIUM (Gd)	12.5 %	2
HOLMIUM (Ho)	6.3 %	1
ERBIUM (Er)	12.5 %	2
THULIUM (Tm)	0.0 %	0
YTTERBIUM (Yb)	0.0 %	0
LUTETIUM (Lu)	6.3 %	1
OTHER	31,3 %	5
ANSWERED QUESTION	16	
SKIPPED QUESTION	16	

7.18 If possible, please indicate your suppliers of the above-mentioned elements.

IN BRACKETS: RESPECTIVE ANSWER TO QUESTION 17
– SGL carbon (graphite)
– indirect purchasing of electronic components (we have to rely on suppliers)
– various (graphite, tungsten)
– pemco, ferro the enamel suppliers (cobalt)
– not possible according internal rules (none of the mentioned elements)
– braze alloy suppliers (germanium, indium)
– multiple sources: - DKSH – BIBUS (titanium for Medical Devices) Product manufacturers with need in analysis (cobalt, magnesiun, molybdenum, niobium, tantalum, tungsten, yttrium)

7.19 What is the amount of the critical elements you mentioned in relation to the other materials used for the product?

ANSWER OPTIONS	Response Percentage	Response Count
<10 %	81,3 %	13
10–30 %	18,8 %	3
>30 %	0,0 %	0
Comment		2
ANSWERED QUESTION		16
SKIPPED QUESTION		16

7.20 What is the Percentageage of the value of critical elements and their processing in view of the overall value of the product?

ANSWER OPTIONS	Response Percentage	Response Count
<10 %	68,8 %	11
10-30 %	25,0 %	4
>30 %	6,3 %	1
Comment – can rise up to 20 % in certain cases		1
ANSWERED QUESTION		16
SKIPPED QUESTION		16

7.21 Please state three materials critical for your company and indicate on scale 1 to 3 if the price volatility of the materials over the last 5 years.

Anwered by nine people: cerium (2 times), gadolinium, germanium, graphit, holmium, indium, iridium, lanthanum (2 times), luthetium, magnesium (2 times), molybdenum, palladium, platinum (2 times), tungsten (2 times, yttrium.
Volatility was stated as being average in most cases.

7.22 Please indicate on a scale 1 to 5 if the quantities required by your companies have in - or decreased over last 5 years. Use the same materials as in the previous question.

See above. Quantities have merely a tendency to rise.

7.23 The previous questions concerned the role of critical materials in your current products. Do you expect the role of critical materials to decrease or to increase, due to new product developments? Can you give examples?

- increase because of increasing production numbers
- We expect an increase but on a low level. The Kayem alloys are quite exotic with a small consumption (< 100 t / year, i.e. 1 t Mg / year)
- increasing do to more products with electronic components
- Hard to say, mostly regulations which prohibit certain elements are the main limiting factor at the moment, not the insufficient supply of them, since we do only use them inderectly, when they are already included in components.
- we don't expect a change
- It will for sure increase.
- Decrease due to R&D activities to substitute critical elements within brazing alloys
- depends of customers
- Role of Pd increases due to hydrogen membranes (new product)

7.24 Did your company experience issues with supply of critical materials over the last 5 years?

ANSWER OPTIONS	Response Percentage	Response Count
YES	27,8 %	5
NO	72,2 %	13
If yes : Which materials were affected? Please describe, if possible, the problem and the reaction of your company. – Scandiumoxide, availability discussions with supplier reaction : higher ereserve stocks – extremely raised prize of rare earth metals. Reaction was investigations to reduce the amount necessary. – Tungsten as part of tungsten carbide/hard metal – Titanium : Quality-up-and downturns availability time – Titanium and palladium, both due to geopolitical reasons		5
ANSWERED QUESTION	18	
SKIPPED QUESTION	14	

7.25 Do critical materials play a role in the risk management of the company?

ANSWER OPTIONS	Response Percentage	Response Count
YES, this is an active part of the management.	27,8 %	5
NO, not at this moment, but there are plans to include it in the near future.	11,1 %	2
NO, critical materials are not involved in the risk management of the company.	61,1 %	11
ANSWERED QUESTION	18	
SKIPPED QUESTION	14	

7.26 Which (material specific) measures are/will be taken to deal with material criticality? (Multiple answers possible)

ANSWER OPTIONS	Response Percentage	Response Count
Substitution of critical materials by other, less critical materials	44,4 %	8
Efficient use of critical materials in products and production	44,4 %	8
Spreading of risk by choosing multiple suppliers from different countries	55,6 %	10
Stock piling of critical materials	22,2 %	4
I do not know / not applicable	27,8 %	5
Else, namely:	11,1 %	2
ANSWERED QUESTION	18	
SKIPPED QUESTION	14	

7.27 If, for example, one or more critical materials relevant for your company is/are not available any more within the next e.g. 6 months, which steps could your company take right now in order to avoid possible problems?

- 6 months would not be critical, stock are suffcient
- At the moment we do not know how to replace Mg
- chosing another supplier
- use of alternative material
- only to buy on stock before
- Enhanced R&D efforts for substitution materials.
- critical materials are in stock for at leat one year
- not relevant to us
- stock piling

7.28 Which change dœs your company expect within 3-5 years concerning critical materials ?

ANSWER OPTIONS	Response Percentage	Response Count
Critical materials are a much bigger problem and limit the production of certain components and or products.	13,3 %	2
Critical materials are a much bigger problem, but due to the timely reaction of the company we can deal with possible limitations.	40,0 %	6
Critical materials are not a problem anymore, due to the discovery of new material sources.	26,7 %	4
Critical materials have never been a problem.	20,0 %	3
ANSWERED QUESTION	15	
SKIPPED QUESTION	17	

7.29 Dœs the company see any potential in the critical materials ?

ANSWER OPTIONS	Response Percentage	Response Count
YES, there are already developments in the company.	33,3 %	6
YES, there are plans, but no concrete developments yet.	11,1 %	2
NO, this phenomenon is actually a threat for the company.	11,1 %	2
I do not know / have no opinion on this matter.	44,4 %	8
ANSWERED QUESTION	18	
SKIPPED QUESTION	14	

7.30 In the list hereunder several possibilities are stated which could provide support to the company in limiting the risk the critical materials are posing. Which ones would your companies like to use? (Multiple answers possible)

ANSWER OPTIONS	Response Percentage	Response Count
Regular meetings with updates on the latest developments concerning this phenomenon.	16,7 %	3
Swift expert check-ups of the company to determine the risk the critical materials are posing.	5,6 %	1
Hiring experts on a long term to gain advice on strategy (consultants)	5,6 %	1
Insight in quantities of critical materials in all products and components of the company.	27,8 %	5
Personnel training to increase knowledge in this field.	27,8 %	5
Use of databases covering data and development of critical materials.	50,0 %	9
None	11,1 %	2
Else, namely	11,1 %	2
ANSWERED QUESTION	18	
SKIPPED QUESTION	14	

7.31 If the use of a database would be an option for you, please indicate the data you would be interested in : (Multiple answers possible)

ANSWER OPTIONS	Response Percentage	Response Count
Critical materials properties	44,4 %	8
Economic evolution of critical material	38,9 %	7
Financial evolution of critical material	33,3 %	6
Regulatory issues regarding critical materials (e.g. Dodd Frank Act)	83,3 %	15
Other, namely	5,6 %	1
ANSWERED QUESTION	18	
SKIPPED QUESTION	14	

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