CRM_InnoNet

Substitution of Critical Raw Materials

Deliverable report

D4.3 Internal report summarising the results of the transport sector

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Deliverable description

This report summarises the results of supply chain analysis to identify critical raw material (CRM) dependencies and Europe's role in the supply chain for specific applications in the transport sector.

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Abbreviations

CMH	Conventional Midsize Car
CML	Conventional Midsize Car
CLM	Conventional Large Car
CRM	Critical raw material
ECU	electronic control unit
ELV	End of life vehicles
EV	Electric Vehicle
FCV	Fuel Cell Vehicle
GHG	Greenhouse gas
HMM	Hybrid Midsize Car
HSE	Health safety and environment
MDP	Mineral Resource Depletion
R&D	Research & development
REE	Rare earth element
SUV	Sport utility vehicle

Elements

Ag	Silver
Be	Beryllium
Ce	Cerium
Co	Cobalt
Dy	Dysprosium
Er	Erbium
Eu	Europium
Ga	Gallium
Gd	Gadolinium
Ge	Germanium
Ho	Holmium
In	Indium
Ir	Iridium
La	Lanthanum
Li	Lithium
Lu	Lutetium
Mg	Magnesium
Nb	Niobium
Nd	Neodymium
Pd	Palladium
Pr	Praseodymium
Pt	Platinum
Re	Rhenium
Rh	Rhodium
Ru	Ruthenium
Sb	Antimony
Sc	Scandium
Sm	Samarium
Ta	Tantalum
Tb	Terbium
Tm	Thulium
W	Tungsten
Y	Yttrium

1 Introduction and objectives of supply chain analysis

The transport sector produces products and services both for consumers, industries and professional users. Because the focus of this study is critical raw materials (CRMs), services were excluded. The specific emphasis in this analysis was on aero and road transports. CRMs are also used in other transport sectors such as railway transport or sea transports though those are not included in this study. Examples of products used in the road and air transport sectors that might include CRMs and play a role for the European economy include:

- Automobiles which transport less than 10 persons
- Heavy vehicles
- Commercial Aeroplanes
- Goods vehicles
- Buses
- Bicycles
- Helicopters

Rapid changes, due to new environmental regulations (EURO V, VI etc.), as well as new consumer demands (low cost cars, hybrids, electric vehicles etc.), are characteristic for the transport sector. Because of lean management and rising manufacturing costs, the production and assembly of components are often moved to countries with lower labour costs.

The objective of this study is to identify applications in the transport sector that are CRM dependent and important to the European economy. The specific application supply chain analyses carried out as a part of this study help detect possible bottlenecks within the supply chain and identify Europe's role throughout the chain. As a result, a better sense of potential CRM supply risk to European industry will be realised.

This analysis of the transport sector is complemented by parallel analyses completed by CRM_InnoNet for the energy sector (Brunot et al. 2013) and ICT and electronics sector (Bachér et al., 2013).

2 Supply chain analysis methodology

In order to have a unified and transparent approach for selection of applications for supply chain analysis and to enable direct comparison of the applications chosen, a common methodology was developed and applied for the three sectors studied. The scheme of the application selection for the supply chain analysis is presented in Figure 1.

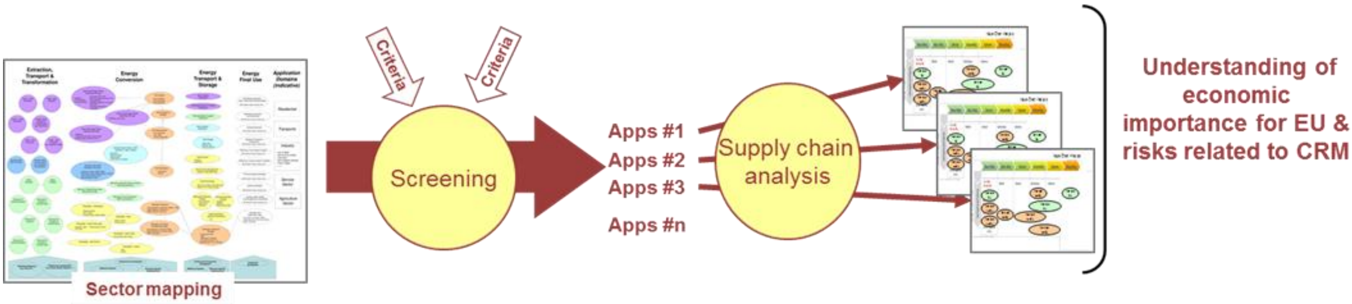

Figure 1: Approach to selection of applications for supply chain analysis.

The selection process of applications for the supply chain analysis can be divided into two steps. In the first step the quantity of applications was reduced by screening to approximately five applications. The second step comprised of supply chain analysis, including statistical analysis and examination of market and technical quantitative and qualitative data by experts. A more detailed description of the methodology applied in supply chain analysis is described in Appendix 1.

3 Screening of applications for supply-chain analysis

Critical raw materials are widely used and vital to the function of many different applications in the transport sector. Screening to reduce the quantity of applications to a manageable amount and to highlight the most important applications for EU economy is therefore necessary. The selection of applications for supply chain analysis is based on the process presented in previous section and in Appendix 1.

3.1 Identification of CRM dependencies and current status

Applications from the transport sector have been listed for identification of CRM dependencies and current status. The CRMs required for the functioning of the applications have been identified. In Table 1 a summary of applications with possible CRM and their current status is presented.

Table 1: Summary of CRM dependencies and identification of applications which will be further considered for analysis.

Application	CRM-Use	Progress to evaluation of economic importance
Automobile	Pt, Pd, Rh, Ta, Nb, Mg, Sb, Nd, Gd, Be, In, Ce, Dy, La, Tb, Tm, Y, Er, Eu, Ga, Ho, Graphite	**Yes**
Heavy vehicles	Pt, Pd, Rh, Ta, Nb, Mg, Sb, Nd, Gd, Be, In, Ce, Dy, La, Tb, Tm, Y, Li, Co, Ag	**Yes**
Buses	Assumed similar to auto/heavy vehicles	**Yes**
Goods vehicles	Assumed similar to auto/heavy vehicles	**Yes**
Catalysts for petrochemical refining and biofuels production	Pt, Pd, Rh, Ir Ru, Re, Co, W, La, Ce, Pr, Nd, Lu	**Yes**
Commercial aeroplanes	Sb, Ge, Mg, Gd, Rh, Pd, Be, Pr, Sm, W, Ta, Ru, Nb, Y	**Yes**
Motorcycle	Assumed similar to automobile	**Yes**
Bicycle	Mg, Sc, Be	**Yes**
Helicopter	Assumed similar to aeroplane	**Yes**

3.2 Preliminary evaluation of European economic importance

In the examination of European economic importance, information from Eurostat's PRODCOM database has been used. The applications identified above were 'matched' with the most relevant product group according to PRODCOM's classification system. Where multiple PRODCOM groups are relevant to a particular application, those groups are aggregated. In Table 2 the corresponding PRODCOM groups for the selected applications are presented.

Table 2: Corresponding PRODCOM group(s) for the applications selected for European economic evaluation.

Application	Corresponding PRODCOM group (including code)
Automobile	29102100 - Vehicles with spark-ignition engine of a cylinder capacity <= 1 500 cm³, new 29102230 - Motor vehicles with a petrol engine > 1500 cm³ (including motor caravans of a capacity > 3000 cm³) 29102330 - Motor vehicles with a diesel or semi-diesel engine > 1500 cm³ but <= 2500 cm 29102310 - Motor vehicles with a diesel or semi-diesel engine <= 1500 cm³
Heavy vehicle	29102340 - Motor vehicles with a diesel or semi-diesel engine > 2500 cm³ 29104130 - Goods vehicles with a diesel or semi-diesel engine, of a gross vehicle weight > 5 tonnes but <= 20 tonnes (including vans) (excluding dumpers for off-highway use) 29104140 - Goods vehicles with compression-ignition internal combustion piston engine (diesel or semi-diesel), of a gross vehicle weight > 20 tonnes (excluding dumpers designed for off-highway use)"
Goods vehicles (not heavy vehicles)	29104110 - Goods vehicles with a diesel or semi-diesel engine, of a gross vehicle weight <= 5 tonnes (excluding dumpers for off-highway use) 29104200 - Goods vehicles, with spark-ignition internal combustion piston engine; other goods vehicles, new
Bus	29103000 - Motor vehicles for the transport of more than 10 persons
Commercial aeroplanes	30303200 - Aeroplanes and other aircraft of an unladen weight <= 2000 kg, for civil use 30303300 - Aeroplanes and other aircraft of an unladen weight > 2000 kg, but <= 15000 kg, for civil use 30303400 - Aeroplanes and other aircraft of an unladen weight > 15 000 kg, for civil use
Motorcycle	30911100 - Motorcycles, and cycles fitted with an auxiliary motor, with an engine capacity <= 50 cm³ 30911200 - Motorcycles with reciprocating internal combustion piston engine > 50 cm³
Bicycle	30921000 - Bicycles and other cycles (incl. delivery tricycles), non-motorized 30921030 Non-motorised bicycles and other cycles, without ball bearings (including delivery tricycles) 30921050 - Non-motorized bicycles and other cycles with ball bearings (including delivery tricycles)
Helicopter	30303100 - Helicopters, for civil use

3.3 Selection of applications for CRM supply chain analysis

Data from PRODCOM was extracted and analysed for each application in order to address whether criteria presented in the methodology (Appendix 1) are met. In Table 3 the economic importance of applications is presented.

Table 3: Economic screening for CRM supply chain analysis. Data from 2012, except sector values from 2011.

Sector and its production value (2011)	Application	CRM-Use	EU economic importance			Progress to full Supply chain analysis
			Value (2012)	Share of prod. >25%	Share of products in sector >0.2%	
Manufacture of motor vehicles, trailers and semi-trailers €678906 M	Automobiles	Pt, Pd, Rh, Ta, Nb, Mg, Sb, Nd, Gd, Be, In, Ce, Dy, La, Tb, Tm, Y, Er, Eu, Ga, Ho, Graphite	223808 M€	95%	39.97%	Yes
	Heavy vehicles	Pt, Pd, Rh, Ta, Nb, Mg, Sb, Nd, Gd, Be, In, Ce, Dy, La, Tb, Tm, Y, Li, Zn, Co, Ag	33369 M€	91%	4.9%	Yes
	Buses	Assumed similar as auto/heavy vehicles	3855 M€	86%	0.57%	(Yes)
	Goods vehicles	Assumed similar as auto/heavy vehicles	23878 M€	85%	3.52%	(Yes)
Manufacture of other transport equipment €198311 M	Helicopter	Assumed similar as aeroplane	3709 M€	83%	1.9%	(Yes)
	Commercial aeroplanes	Sb, Ge, Mg, Gd, Rh, Pd, Be, Pr, Sm, W, Ta, Ru, Nb, Y	7850 M€	27%	2.5%	Yes
	Motorcycle	Assumed similar as automobile	3463 M€	68%	1.6%	(Yes)
	Bicycle	Mg, Sc, Be	2165 M€	66%	1.1%	No

Three applications were selected for supply chain analysis. Those applications are:

- Automobile
- Heavy vehicle
- Commercial aeroplane

It was decided that a separate supply chain analysis was not required for buses and goods vehicles, as the CRM dependencies would be similar to heavy vehicles. Similarly, separate supply chain analysis was not conducted for motorcycles, since the CRM dependencies were considered similar enough to an automobile. Helicopters were assumed to be somewhat similar to aeroplanes, mostly because of the similarities in navigation systems and electronics. Hence, no separate supply chain analysis was made for the helicopter. Although bicycles passed the screening criteria, a full supply chain analysis was not conducted due to the limited number of CRMs involved. Alloys containing CRMs are mostly used in more professional bicycles and CRM dependency for regular bicycles are estimated to be very low.

Because of the complexity of the applications analysed for the transport sector, which contain a plethora of CRM-containing components, an additional economic screening was made for the automobile, heavy vehicle and the commercial aeroplane. This extra step was made in order to give a more detailed overview of the components of transport sector applications that, in themselves are important for the European economy. This also makes this report more in line with the parallel CRM_InnoNet reports on the Energy sector (Brunot et al. 2013) and ICT and electronics sector (Bachér et al., 2013). In these sectors applications tends to be less complex or at least have less CRM-containing parts. However it is important to remember that parts, of for example a car, which contains CRM can be essential for European industry and jobs even though that part is produced outside Europe.

4 Value-Chain analysis of applications

4.1 *Automobile*

Table 4: Structural composition of automobile.

	CRM Content	Comments	Identified PRODCOM categories
Automobile			29103000 Motor vehicles for the transport of <= 10 persons
Exhaust after treatment			29323063 Silencers and exhaust pipes; parts thereof
Autocatalysts	Pt, Pd, Rh, Ce		24413030 Platinum, palladium, rhodium, iridium, osmium and ruthenium, unwrought or in powder form 24413070 Platinum catalysts in the form of wire cloth or grill
Chassis			29104400 Chassis fitted with engines, for tractors, motor cars and other motor vehicles principally designed for carrying people, goods vehicles and special purpose vehicles including for racing cars
Ferro-alloys			24101290 Other ferro alloys n.e.c.
Superalloys	Ta		24453055 Beryllium, chromium, germanium, vanadium, gallium, hafnium (celtium), indium, niobium (columbium), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium)
HLSA steels	Nb		24453055 Beryllium, chromium, germanium, vanadium, gallium, hafnium (celtium), indium, niobium (columbium), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium) 24101290 Other ferro alloys n.e.c. 24312050 Sections, of alloy steel other than stainless, cold finished or cold formed (e.g. by cold-drawing)
Cast alloy car parts	Mg		24453025 Magnesium and articles thereof (excluding waste and scrap), n.e.c.
Wrought alloys	Mg		24453025 Magnesium and articles thereof (excluding waste and scrap), n.e.c.
Aluminium alloys for press-formed body parts	Mg		24453025 Magnesium and articles thereof (excluding waste and scrap), n.e.c. 24421153 Unwrought aluminium alloys in primary form (excluding aluminium powders and flakes) 24421155 Unwrought aluminium alloys in secondary form (excluding aluminium powders and flakes)
Lead alloys	Sb		N.A
Seating			29321000 Seats for motor vehicles
Magnets	Rare earths	Energy	25992995 Permanent magnets and articles intended to become permanent magnets, of metal
Steering	Nd		29323067 Steering wheels, steering columns and steering boxes; parts thereof
Magnets	Rare earths	Energy	25992995 Permanent magnets and articles intended to become permanent magnets, of metal
Brake system	Gd, Rh, Pd		29323020 Brakes and servo-brakes and their parts (excluding unmounted linings or pads)
Anti-lock brake systems	Be		**N.A**
Secutity, airbag	In, Er		29322050 Airbags with inflator system and parts thereof
Automobile connectors for air-bag crash senso	Be		
Fluorescent lighting	In, Ce		27403930 Electric lamps and lighting fittings, of plastic and other materials, of a kind used for filament lamps and tubular fluorescent lamps
Loudspeakers	Nd, Dy	ICT	
Magnets	Rare earths	Energy	25992995 Permanent magnets and articles intended to become permanent magnets, of metal
LED	Ce,Eu,Ga,Gd,Ho In,La,Ta,Tb,Tm, Sb,Y	ICT	
Flame retardants	Sb		**N.A**
Rubber tyres	Sb		20165960 Natural and modified polymers, in primary forms (including alginic acid, hardened proteins, chemical derivatives of natural rubber)
Modifier for aluminium and magnesium castings	Be		24531010 Light metal castings for land vehicles excluding for locomotives or rolling stock, construction industry vehicles 24531020 Light metal castings for transmission shafts, crankshafts, camshafts, cranks, bearing housings and plain shaft bearings (excluding for bearing housings incorporating ball or roller bearings)
Lubricants	Graphite		20594157 Lubricating preparations containing < 70 % of oils obtained from petroleum or bituminous minerals excluding preparations for the treatment of textiles, leather, hides and furskins
Heat exchangers	Mg		28251130 Heat exchange units 24453025 Magnesium and articles thereof (excluding waste and scrap), n.e.c.

In this section, automobiles for transport of less than 10 people are analysed. An automobile has several parts that contain CRMs. A structural composition of the automobile is presented in Table 4. Only the parts that contain CRMs are included in Table 4 and in the supply chain analysis. The parts that have ICT or Energy written in the comments column are further investigated in the parallel analyses for the energy sector (Brunot et al. 2013) and ICT and electronics sector (Bachér et al., 2013).

In order to show which CRM containing parts of automobiles have the largest production in Europe an economic screening was made on those parts. The PRODCOM groups used for the different parts of the car are shown in Table 5. In some cases, there is no obvious match or an application might be spread across many several PRODCOM groups. For transport applications this problem mostly occurs at the component level, as many of the parts used in vehicles are also used in other applications. This means that the produced value for e.g. brakes, include all brakes not only the ones used in the specific application assessed in the supply chain analysis.

The economic screening of the applications is shown in Table 6. Some of the parts that contain CRM that can be seen in Table 4 are not included in the economic screening since they have been covered by either the ICT sector report or the energy sector report. Examples are LEDs and permanent magnets.

Table 5: Corresponding PRODCOM group(s) for the applications on the first sub-level of the car.

Sub-level Application	Corresponding PRODCOM group (including code)
Auto catalyst	24413070 - Platinum catalysts in the form of wire cloth or grill
Chassis	29104400 - Chassis fitted with engines, for tractors, motor cars and other motor vehicles principally designed for carrying people, goods vehicles and special purpose vehicles including for racing cars
Seating	29321000 - Seats for motor vehicles
Steering	29323067 - Steering wheels, steering columns and steering boxes; parts thereof
Brake system	29323020 - Brakes and servo-brakes and their parts (excluding unmounted linings or pads)
Security airbag	29322050 - Airbags with inflator system and parts thereof
Fluorescent lighting	27403930 - Electric lamps and lighting fittings, of plastic and other materials, of a kind used for filament lamps and tubular fluorescent lamps
Rubber	20165960 - Natural and modified polymers, in primary forms (including alginic acid, hardened proteins, chemical derivatives of natural rubber)
Modifier for aluminium and magnesium castings	24531010 - Light metal castings for land vehicles excluding for locomotives or rolling stock, construction industry vehicles 24531020 - Light metal castings for transmission shafts, crankshafts, camshafts, cranks, bearing housings and plain shaft bearings (excluding for bearing housings incorporating ball or roller bearings)
Lubricants	20594157 - Lubricating preparations containing < 70 % of oils obtained from petroleum or bituminous minerals excluding preparations for the treatment of textiles, leather, hides and furskins
Heat exchangers	28251130 - Heat exchange units

Table 6: Economic screening for CRM supply chain analysis. Data from 2012, except sector values from 2011.

Sector and its production value (2011)	Sub-level Application	CRM-Use	EU economic importance		
			Value (2012)	Share of prod. >25%	Share of products in sector >0.2%
Manufacture of motor vehicles, trailers and semi-trailers €678906 M	Auto catalyst	Pt, Pd, Rh, Ce	31 M€	21%	0.01%
	Chassis	Ta, Nb, Mg, Sb	1587 M€	97%	0.23%
	Seating	Nb	12010 M€	99%	1.77%
	Steering	Nd	7452 M€	88%	1.10%
	Brake system	Gd, Rh, Pd, Be	7000 M€	84%	1.03%
	Security airbag	In, Er, Be	3118 M€	90%	0.46%
Manufacture of electrical equipment €272903 M	Fluorescent lighting	In, Ce	2952 M€	63%	1.08%
Manufacture of chemicals and chemical products €200000 M	Rubber	Sb	663 M€	75%	0.33%
	Lubricants	Graphite	1119 M€	91%	0.56%
Manufacture of basic metals €348075 M	Modifier for aluminium and magnesium castings	Be	656 M€	100%	0.19%
Manufacture of machinery and equipment n.e.c. €553727 M	Heat exchangers	Mg	5223 M€	92%	1.00%

Critical raw materials in an automobile system are for example found in the exhaust after treatment system. In the catalytic converter harmful substances in the exhaust, such as carbon monoxide, nitrogen oxides and unburnt hydrocarbons are converted to less harmful substances. Platinum (Pt) is the most widely used catalyst but palladium (Pd) and rhodium (Rh) are also used. While platinum is used both as a reduction and oxidation catalyst, rhodium is only a reduction catalyst and palladium an oxidation catalyst. Cerium oxide (CeO_2) is also used in catalytic converters; cerium (IV) oxide can give up oxygen without decomposing and is therefore used to “store oxygen” since oxygen is necessary for the oxidation reactions.

The chassis contains some parts that are made of high strength steel or ultra-high strength steel, these parts usually have a key role for safety reasons, for example pillars that hold the windscreen. The alloys contain small amounts of niobium (Nb) or tantalum (Ta). High strength steel is also used in the seats of the car. The steering, the brake system, the security system and the heat exchanger all contain CRMs.

Electronics play a more and more central role in cars. Basic vehicles have at least around 30 electronic control units (ECUs) while luxury cars might have as many as 100 (New York Times, 2010). This trend renders a very large amount of the functions in the car dependent on electronics, and therefore CRMs. A few examples of systems that are dependent on ECUs in a car are fuel injection control, cooling systems, anti-lock breaking systems, air bags and adaptive cruise control systems. Because of the great use of ICT products in general, and the large amount of CRMs used in those products, ICT was the subject of a separate report (Bachér et al., 2013).

Because of the large amount of electronic motors used in modern cars, e.g. for adjusting the seats, in the steering system and in the climate system, permanent magnets containing rare earth elements, plays an important role for the car industry. However, electric motors used for those applications are small and have permanent magnets of typically a few grams. In a future with an increased amount of electric vehicles or hybrid vehicles permanent magnet would be of even greater importance. An electric motor of 50 kW used in a hybrid vehicles uses about 1.3 kg of permanent magnets.

The largest quantities of CRM in a car can be found in metallurgical, catalytic and electrical applications (Cullbrand & Magnusson 2012). The mass distribution of CRMs in a conventional mid-size car can be found in Figure 2.

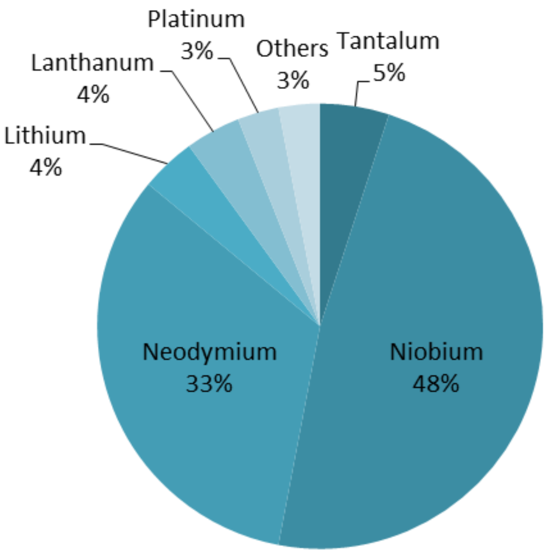

Figure 2: Mass distribution of critical elements (Cullbrand & Magnusson 2012).

4.1.1 Analysis of CRM-related automobile market and supply chain

Economics

The automobile market is characterised by a slow but continuous global growth since 1998. Europe is a mature market, but the liberalization of the market in Europe has led to structural changes in automobile distribution. The US market main characteristic is the domination of the "light truck"-segment. The Japanese automobile market has experienced a modest recovery after 2008 (JAMA, 2014). However, the real contender is the new Chinese automobile market and to some extent Eastern Europe. Other new economies of interest for the automobile industry are Turkey, Iran, Brazil, India and Russia.

The regional production of automobiles is presented in Table 7.

Table 7: The European Automobile production by country (in € million), the figures are the sum of prodcom groups 29102100, 29102230, 29102310 and 29102330.(PRODCOM 2012)

Year	Germany	United Kingdom	France	Spain	Slovakia	Italy	EU27 TOTALS
2012	98 578	25 020	18 784	17 989	5 381	4 571	269 518

The automobile market is exposed to many economic and social influence factors. Consumer patterns are changing and the highly competitive and capital intensive nature of the automobile market can lead to tremendous changes and the appearance or disappearance of manufacturers (e.g. Tesla Motors or Saab Motors). The old automobile size segmentations are now replaced by body shape segmentation (SUV, mini-SUV, crossover etc.). In addition, the automobile life cycle is becoming shorter.

Position of EU in supply chain and main actors

The supply chain of automobile consists of several steps. In addition, the supply chain can include parallel streams for different components including CRM. In Figure 3 the supply chain of the automobile is presented.

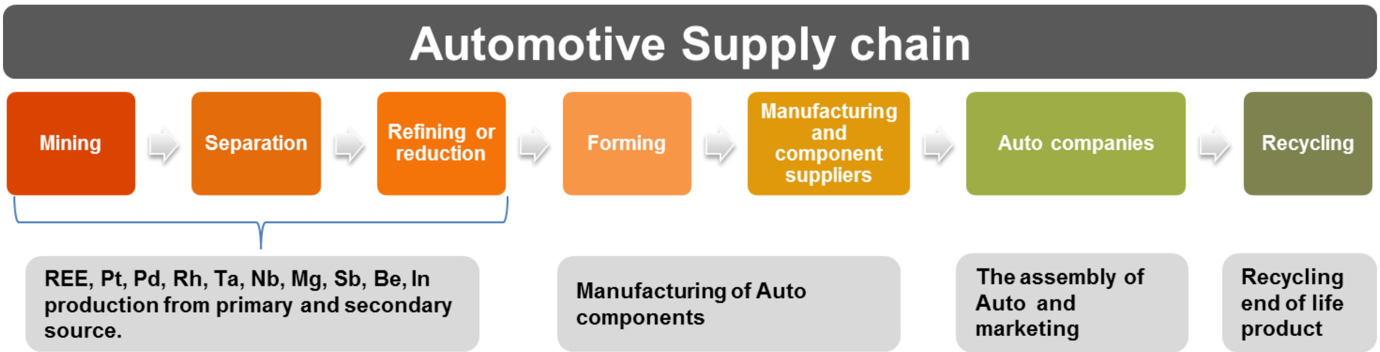

Figure 3: Automobile supply chain.

The supply chain can be roughly divided into four different stages. The first stage is the raw material production from primary or secondary sources. The material in this stage can be in form of pure a metal powder or an alloy. The second stage is the manufacturing of a part or a module. The third stage of the supply chain is the assembly of the components to produce an automobile which can be marketed and sold. The component producers can also have end product production. The final stage of the supply chain is the recycling of end of life products.

About 60 million cars are produced worldwide each year (based on 2011 figures). The major European automobile market producers and their production numbers are (OICA 2012):

- Volkswagen with 8.5 M cars produced in 2012
- PSA with 2.5 M cars
- Renault with 2.3 M cars
- BMW with 2 M cars
- Fiat with 1.5 M cars
- Daimler AG with 1.4 M cars

However, European brands produce a lot of their cars outside Europe. At the same time non-European companies, such as Nissan, Honda and Toyota, have end production of cars in Europe. These companies are contributing to the European economy by job creation and creation of benefits down the car supply chain. For example, Japanese car manufacturers have started manufacturing plants in the EU in order to overcome export tariffs and to lower delivery costs to the European costumers. In 2007 Nissan produced 400,000 cars in their plant in Sunderland, UK. The plant has 6,000 employees. Honda who also has production in the UK has about 3,400 employees at their plant in Swindon. In 2013 the plant produced about 182,000 cars. Toyota has two plants in the UK with a total of 3,800 employees; in 2013 Toyota produced 179,233 cars in their plants in the UK (Toyota UK, 2014a).

In Figure 4 companies related to the automobile supply chain are presented.

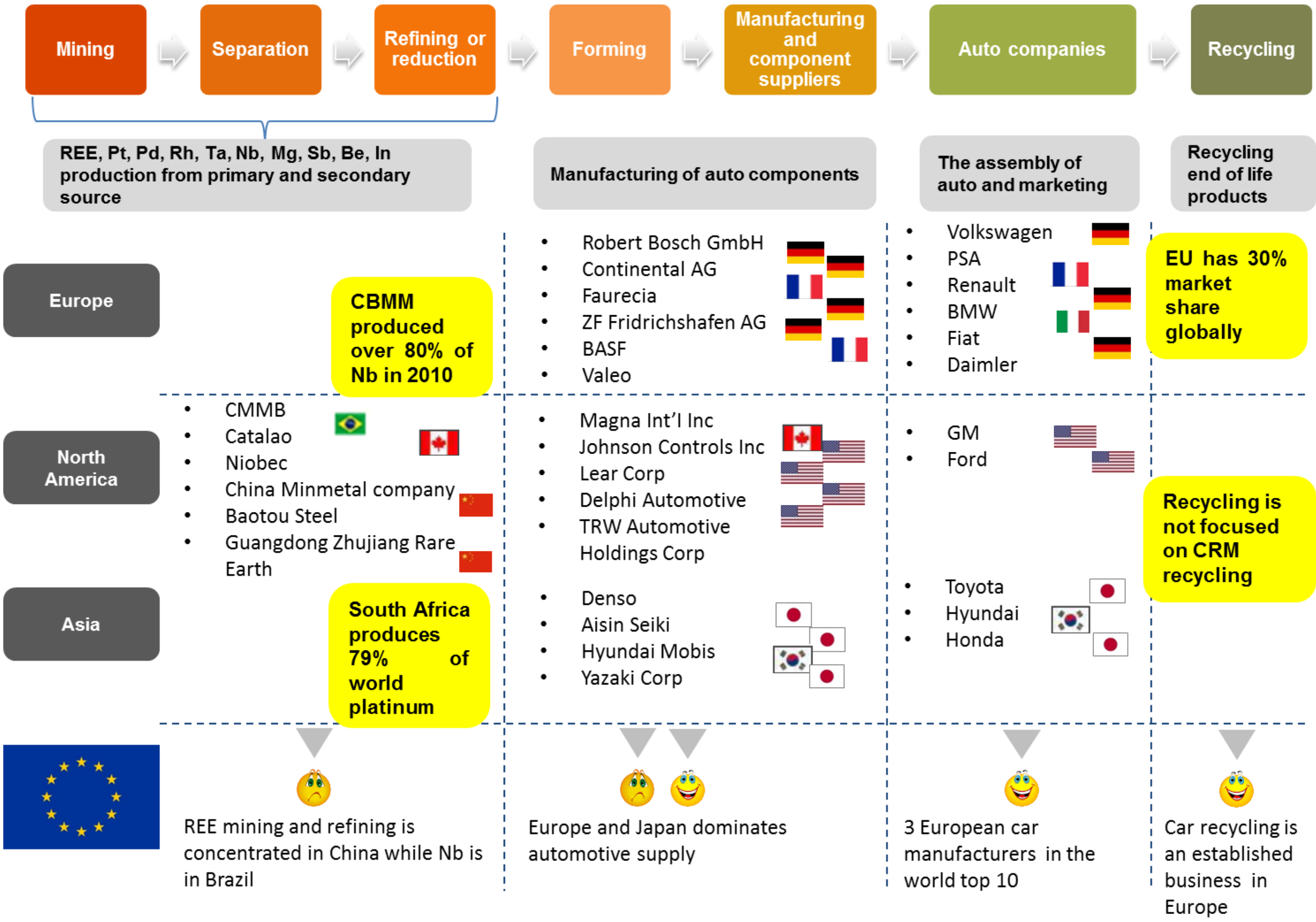

Figure 4: A summary of companies in the automobile's supply chain.

<u>Jobs involved in EU</u>

The NACE-groups called "Manufacturing of vehicles, trailers and semitrailers" and "Manufacturing of other transport equipment" in Eurostat statistics has 2,172,000 and 706,000 employees respectively, see Figure 4. This corresponds to 9.6% of the total workforce in manufacturing in the EU. One should remember that a lot of other enterprises and jobs that are not directly grouped under "transport equipment" are dependent on the transport sector, such as "manufacturing of rubber and plastics products" and "manufacturing of metal products".

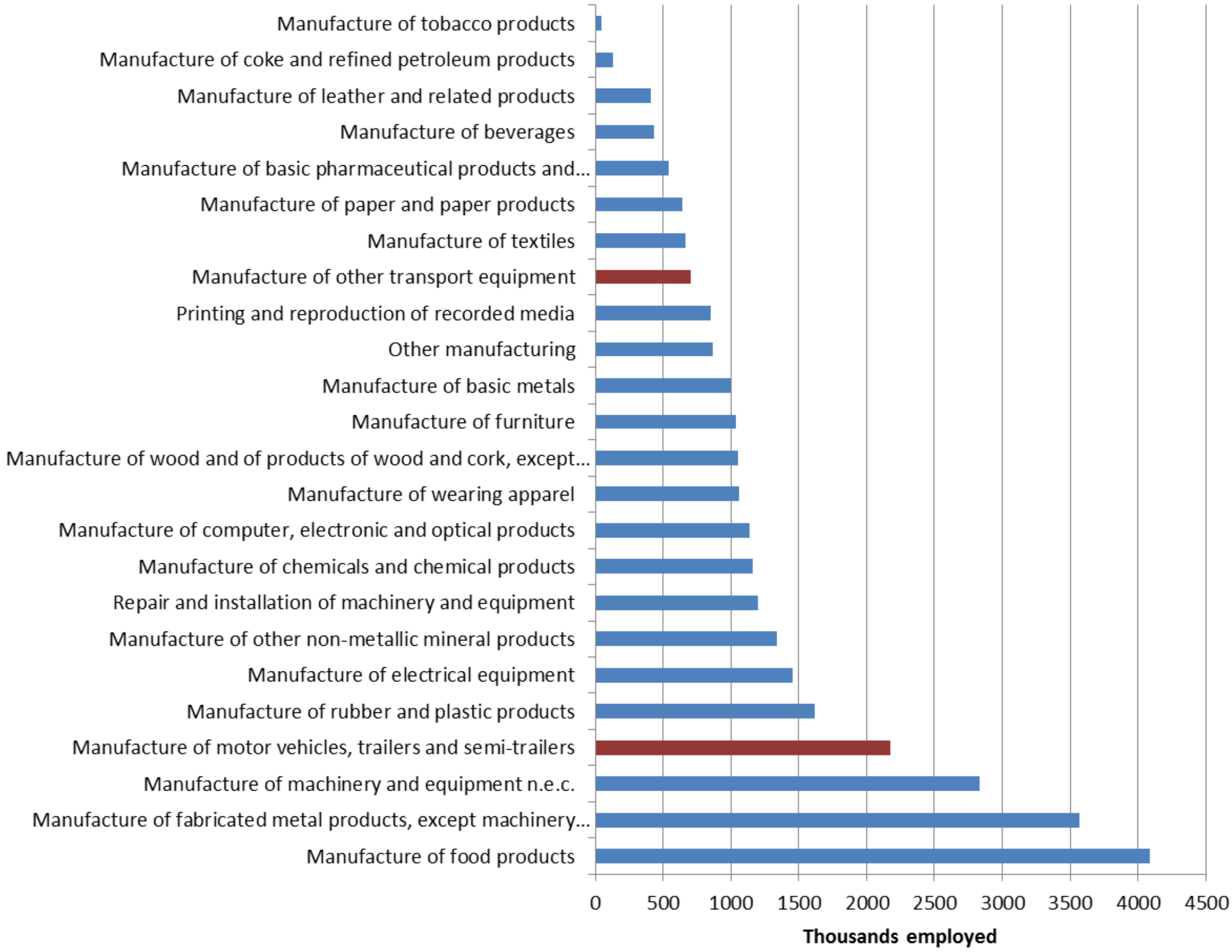

Figure 5: Number of employees in different branches of manufacturing industry in EU. (Eurostat, 2012).

In total, the automobile industry supports more than 12 million European jobs. Increasingly, these are highly skilled jobs. This figure includes activities such as recycling, sales, maintenance and repair of motor vehicles, road transport (passenger transport, taxi operations and freight transport), manufacture of tyres, the construction of highways and roads etc. Yet, many more jobs in other sectors depend on a healthy automobile industry. The data presented above does not report employment in raw material sector (e.g. steel, aluminium, glass, plastic), textile, driving schools, licensing activities, renting of automobiles, vehicle testing, insurance, financing, etc.

EUROSTAT data interpretation

The quantitative supply chain analysis was carried out using data from Europe's PRODCOM database. Data from PRODCOM has been applied to produce a supply chain illustration of which parts of the supply chain have a high production in Europe. Figure 6 shows the PRODCOM groups that are included in the automobile supply chain analysis. In the figure the boxes have been scaled so that the size is relatively proportional to the production value in the EU of that PRODCOM group. The production value for automobiles (PRODCOM groups 29102100, 29102230, 29102310 and 29102330) was about 270,000 million euros in 2012. Note that many PRODCOM groups also include goods produced for industries other than the automotive industry.

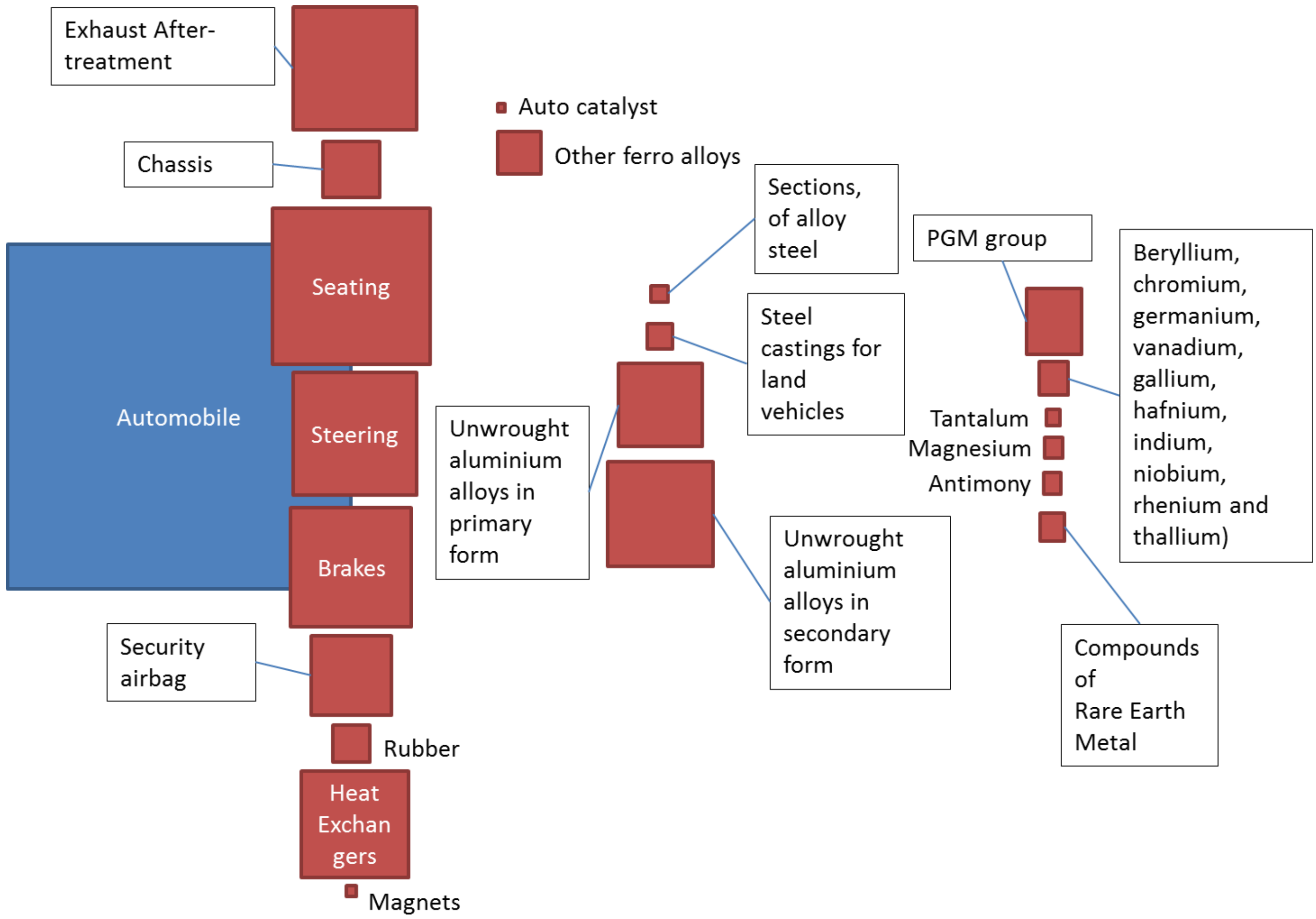

Figure 6: EU production of automobile systems and related (sub)-components and materials. The boxes are scaled in proportion to the produced value in EU 27.

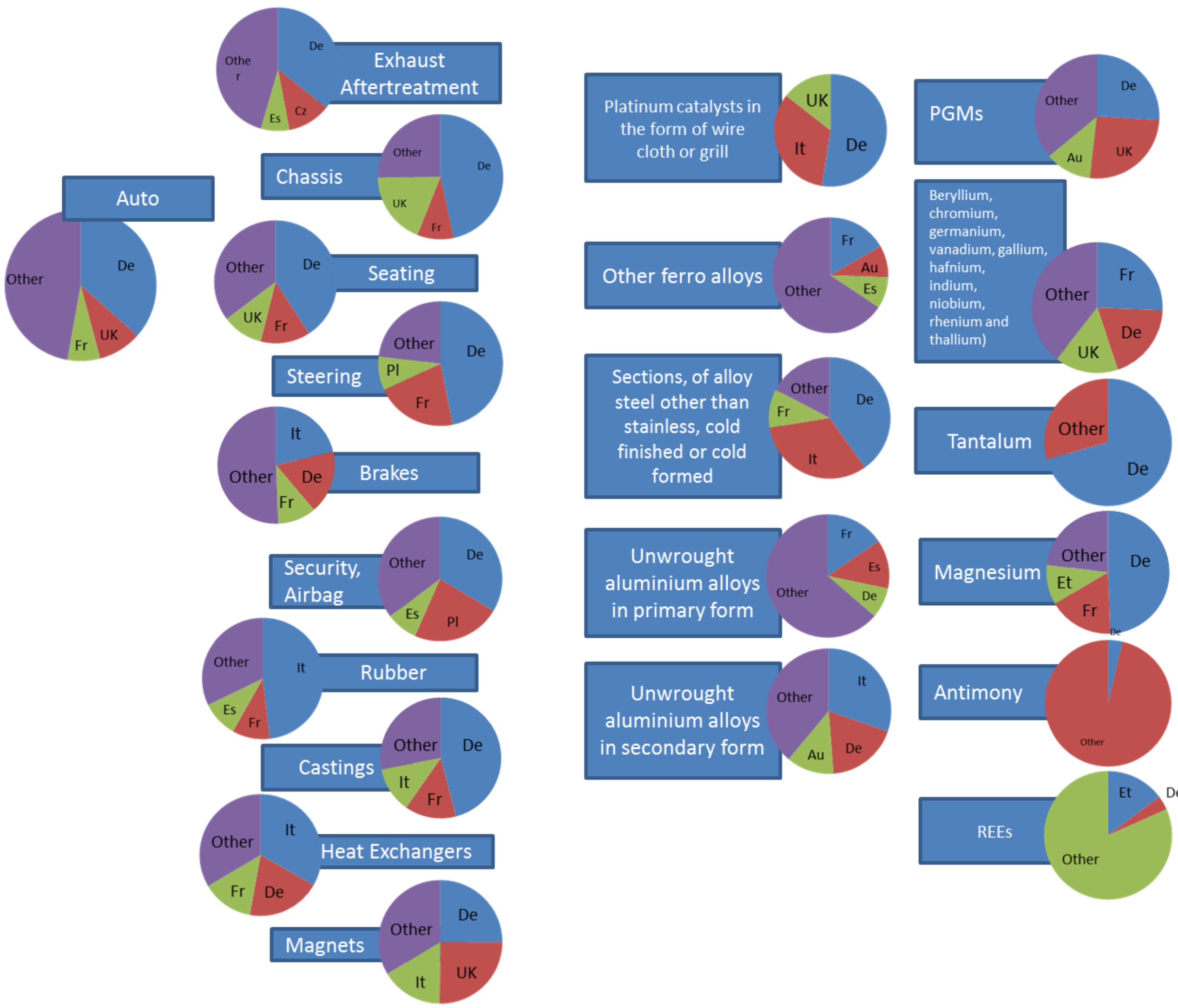

Figure 7: EU production of automobile systems and related (sub)-components and materials. The pie charts show in which countries the largest share of the production takes place.

The production in the supply chain of automobile is concentrated in Central Europe with Germany as the largest producing country in almost every step in the chain. Companies such as Volkswagen and BMW have car production facilities in Germany. In addition, overseas companies like Japanese ones are also producing in Europe with specific partnerships in France, the UK and Germany. Both France and Italy are focused more on component and end application production, while the UK concentrate on component and material production.

It is important to keep in mind that many car manufacturers are part of multinational companies, and some are not based in the EU but still plays a big role for European economy. Examples are Volvo cars owned by Chinese Zhejiang Geely Holding or Toyota manufacturing cars in the UK and employing about 3,800 persons (Toyota UK, 2014b).**Fel! Hittar inte referenskälla.**

In Figure 8 the balance between production, import and export values within automotive supply chain is presented.

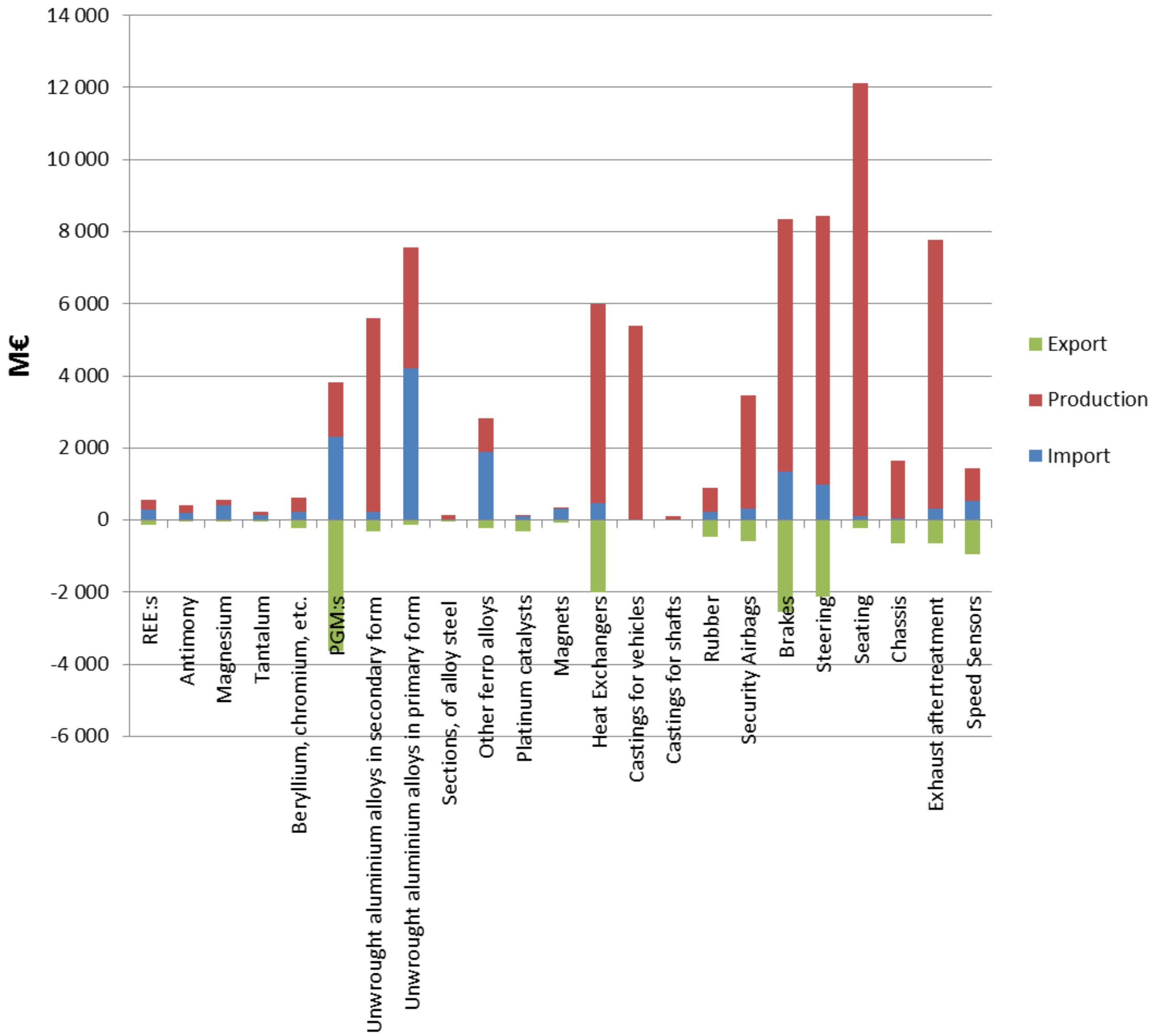

Figure 8: Relationship between production, import and export values for automobile components and materials in Europe 2012. Note the values for components and materials present the whole industry, not only the share used in automobiles.

In Figure 8 production plus import, which are presented on the positive side of x-axis, represent the cumulative value of articles which are within Europe. The value of export is on the negative side and expresses the value of articles which leaves Europe.

Figure 8 shows that the aluminium alloys, ferro alloys and magnets, are mainly imported into Europe. For brakes only around 23% of the whole trade comes from export indicating that a significant quantity of produced and imported brakes are used as components in applications within Europe. A similar structure of the trade balance can be detected for steering and chassis. Raw materials are mainly either produced or imported into Europe. As for exports, platinum group metals make an exception with a large export. However, larger export value than production value in platinum group metals, indicates re-export of imported articles. Generally, a country is involved in re-exports if it has a major hub in a transport network that is used to redistribute goods to neighbouring countries. Re-exports can also stem from trading positions, for instance resulting from strategic stockpiling.

Criticality

Essentiality of the role of CRM

Platinum, magnesium and palladium are essential for the functionality of today's automobiles. No foreseeable change can replace the current setup with Pt, Mg and Pd in the short term (USGS 2013), although substitutes for Pt based on Pd are emerging (Smith 2011). However, when substituting Pt with Pd, the dependency on a CRM is still there.

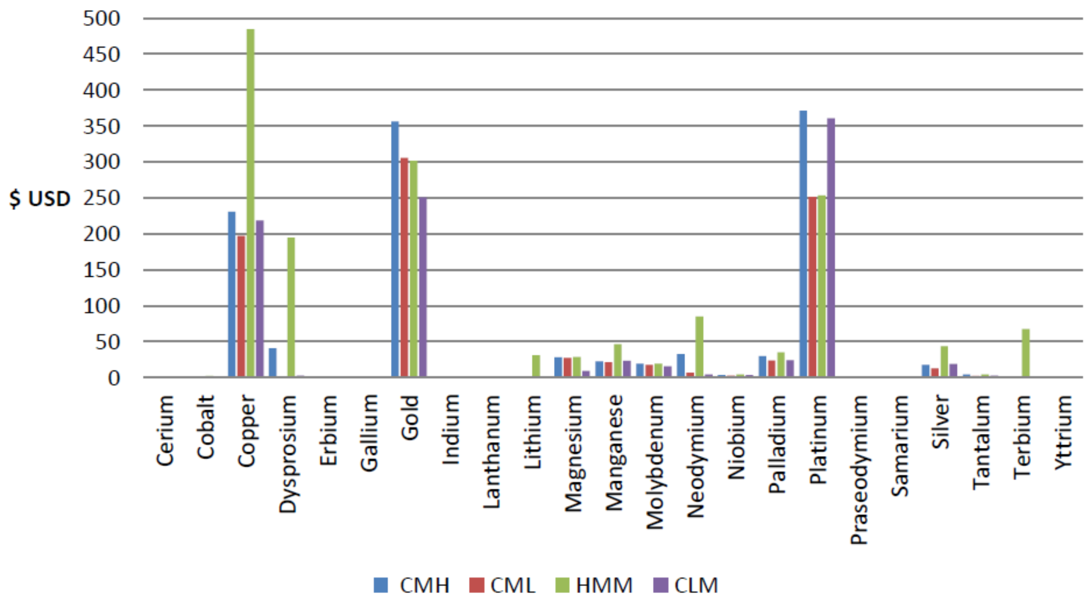

Figure 9: Material costs for 4 car types CMH Conventional Midsize Car, High-Specified CML Conventional Midsize Car, Low-Specified HMM – Hybrid Midsize Car, Medium-Specified CLM – Conventional Large Car, Medium-Specified. Note: materials which are not generally considered critical such as gold and copper can still have a large impact on the cost of production. (Cullbrand & Magnusson 2012)

Figure 9 shows the money spent on selected materials, potentially critical for car industry, used in cars. Out of the three most significant contributors to cost, gold, platinum and copper, only platinum is on the EU list of CRMs. There is no current substitution of platinum in catalytic converters (other than substituting with other CRMs) which makes the high price and the concentration of the platinum production to such few countries (79% of production in South Africa) an important question for car manufacturers. Alloying agents, such as niobium, are used in such small amounts that, though essential for the car, the price for paid for niobium in a car is very low compared to e.g. copper, gold or platinum.

How will the vulnerability of the application evolve?

The demand for platinum (Pt) is being fuelled by the rising production of cars worldwide which increase the need for Pt (there is usually 3 g of Pt in the catalytic converter of a car). While the price of platinum could easily go up following an increased demand in the global automotive industry, it could also go up unexpectedly due to concerns regarding its global supply. Recent turmoil in the mining sector in South Africa, which produces 79% of Pt worldwide (USGS 2013), is worrying. Shortages of platinum and palladium could be expected in the future (Larkin 2013).

Companies in the automobile industry are trying to evade pricing pressures by investing in technological innovations. The electrification of the powertrain increases the use of magnets and neodymium, dysprosium, copper, samarium, silver, terbium, manganese, lithium, platinum and palladium.

Available substitutes

Available substitution options for automobiles are under scrutiny as well as new research that could decrease the need for specific critical raw material (Smith, M. 2011). For instance, it is now possible to manufacture high-efficiency permanent magnet synchronous motors without using rare earth (neodymium, dysprosium) materials (Hitachi 2012). When it comes to electric motors and the use of permanent magnets, an option could be to use a reluctance motor, which uses electro magnets instead of permanent magnets. Reluctance motors can deliver high power to a low cost, but has the trouble of high torque ripple, which means that the torque varies a lot during one revolution. Research is being done on how to best control the reluctance motor, minimize the torque ripple and to minimize noise.For hybrid cars, the general trend is to implement a strategy to recover rare earth materials from end of life parts (Honda 2013).

Tantalum in super alloys can be substituted but most of its applications but with performance losses (USGS, 2013).Composites may replace some of steel parts in the future, as long as that does not result in impairment to the performance of the material. The major challenge is to maintain the same standard when it comes to crash safety as cars using high strength steel parts.

There are no substitutes for the use of platinum group metals (PGMs) in catalytic converters. This makes recycling of these metals crucial. In 2013 an estimated 155,000 kilograms of PGMs was recovered worldwide from new and old scrap (USGS, 2013). Because of the lack of substituting elements or applications recycling of PGMs will be more and more important.

Environmental

Based on a life cycle assessment conducted by Audi, their Audi A6 3.0 TDI average annual fuel consumption is about 6 l of diesel per 100 km, which leads to about 15,000 tons of CO_2 emissions annually (Audi 2013). Vehicles with combustion engines consume higher amounts of energy than hybrids or electric vehicles (EV) but usually they are consuming less energy and material during the manufacturing phase. According to Hawkins et al 2013, Mineral Resource Depletion (MDP) is much larger for EV than for cars with internal combustion engines.

Innovation

The trend is to recycle as much as possible,to minimise the use of CRMs and material in general (Honda 2013) with a lighter weight and the shift to composites when possible.

4.1.2 Automobile – business summary

The qualitative summary of the automobile supply chain is presented in .

Table 8.

Table 8: Qualitative summary table of the automobile supply chain.

Criteria	Sub-criteria	Required input
economic	Economic value of application or area	• The market revenue of automobile manufacturing in Europe was €3,855 million in 2012.
	Position of EU in entire supply chain	• The global market share of European car manufacturers is about 30%. • Component manufacturing (not only production of end product) is also important for EU economy (e.g. seats, steering, brakes). • Out of the CRMs (gold and copper are not defined as CRM) used for the production of a car, most money is spent on platinum (Cullbrand & Magnusson 2012). • Catalytic converter production is dominated by US and European companies such as Bosch, Cummins and Tennecog. However, most production is not in the EU.
	Jobs involved in the EU	• 2.3 M persons are employed in manufacture of automobiles in Europe (2012 figures).
criticality	How essential is the role of the critical material in the application?	• Platinum is essential to catalytic converter production. • Mg is alloyed with aluminium, zinc, copper, nickel, lead, zirconium and other metals used in the automotive industry. • Niobium and tantalum used in high strength steel is essential to ensure safety. • REEs essential for small electric motors.
	How will the vulnerability of the application develop over time?(as a result of RM and market developments)	• Shortages in supply and price increase of platinum and palladium are expected. (Larkin 2013) • The market for automobiles in Europe is shifting to the east where the growth is higher and manufacturing costs lower. • The transition to news fuels (H_2) and powertrains (EV, hybrid, FCV) is adding constraints and can lead to more CRMs in the automobile sector.
	Available substitutes?	• Permanent magnets not using REEs. • Reluctance motor instead of permanent magnet synchronous motors. • Composites may replace some of steel parts. • No non-CRM substitute for PGMs in catalytic converters. • Magnesium has no available substitute.

environmental	Impact on European policies in case of disruption	• Disruption of catalytic converter material or higher price for exhaust after treatments system could favour alternative powertrains such as EV where zero tail emissions could be achieved without “end-of-pipe” technologies. CO_2 emissions and air quality improvement could be paradoxically expected if the shift occurs due to material disruption and if regulations are still hardened.
Innovation	Substitution activities already on-going? What is the status of that research?	• Having more composites and polymer on board instead of metals and alloys is a trend that could grow in the future. • Recycling and minimizing use of PGMs. Replacing Pt by Pd when possible is also under scrutiny.
	Principle of substitution: is substitution conceivable? Potential for Europe	• The extent of how metal and alloys are substituted by polymers and composites is unclear • The leading European air quality standards as well as the positioning of European companies in the exhaust after treatments systems are clear opportunities to export and develop the technology abroad.

4.3 Heavy Vehicle

4.3.1 Heavy vehicle technologies and CRM dependence

Table 9: Composition of the heavy vehicle.

	CRM Content	Comments	Identified PRODCOM categories
Heavy Vehicle			29103000 Motor vehicles for the transport of <= 10 persons
Exhaust after treatment			29323063 Silencers and exhaust pipes; parts thereof
Autocatalysts	Pt, Pd, Rh, Ce		24413030 Platinum, palladium, rhodium, iridium, osmium and ruthenium, unwrought or in powder form 24413070 Platinum catalysts in the form of wire cloth or grill
Chassis			29104400 Chassis fitted with engines, for tractors, motor cars and other motor vehicles principally designed for carrying people, goods vehicles and special purpose vehicles including for racing cars
Ferro-alloys			24101290 Other ferro alloys n.e.c.
Superalloys	Ta		24453055 Beryllium, chromium, germanium, vanadium, gallium, hafnium (celtium), indium, niobium (columbium), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium)
HLSA steels	Nb		24453055 Beryllium, chromium, germanium, vanadium, gallium, hafnium (celtium), indium, niobium (columbium), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium) 24101290 Other ferro alloys n.e.c. 24312050 Sections, of alloy steel other than stainless, cold finished or cold formed (e.g. by cold-drawing)
Cast alloy car parts	Mg		24453025 Magnesium and articles thereof (excluding waste and scrap), n.e.c.
Wrought alloys	Mg		24453025 Magnesium and articles thereof (excluding waste and scrap), n.e.c.
Aluminium alloys for press-formed body parts	Mg		24453025 Magnesium and articles thereof (excluding waste and scrap), n.e.c. 24421153 Unwrought aluminium alloys in primary form (excluding aluminium powders and flakes) 24421155 Unwrought aluminium alloys in secondary form (excluding aluminium
Lead alloys	Sb		N.A
Seating			29321000 Seats for motor vehicles
Magnets	Rare earths	Energy	25992995 Permanent magnets and articles intended to become permanent magnets, of metal
Steering	Nd		29323067 Steering wheels, steering columns and steering boxes; parts thereof
Magnets	Rare earths	Energy	25992995 Permanent magnets and articles intended to become permanent magnets, of metal
Brake system	Gd, Rh, Pd		29323020 Brakes and servo-brakes and their parts (excluding unmounted linings or pads)
Anti-lock brake systems	Be		**N.A**
Secutity, airbag	In, Er		29322050 Airbags with inflator system and parts thereof
Automobile connectors for air-bag crash senso	Be		
Fluorescent lighting	In, Ce		27403930 Electric lamps and lighting fittings, of plastic and other materials, of a kind used for filament lamps and tubular fluorescent lamps
Loudspeakers	Nd, Dy	ICT	
Magnets	Rare earths	Energy	25992995 Permanent magnets and articles intended to become permanent magnets, of metal
LED	[illegible] In,La,Ta,Tb,Tm,Sb, Y	ICT	
Flame retardants	Sb		**N.A**
Rubber tyres	Sb		20165960 Natural and modified polymers, in primary forms (including alginic acid, hardened proteins, chemical derivatives of natural rubber)
Modifier for aluminium and magnesium castings	Be		24531010 Light metal castings for land vehicles excluding for locomotives or rolling stock, construction industry vehicles 24531020 Light metal castings for transmission shafts, crankshafts, camshafts, cranks, bearing housings and plain shaft bearings (excluding for bearing housings incorporating ball or roller bearings)
Lubricants	Graphite		20594157 Lubricating preparations containing < 70 % of oils obtained from petroleum or bituminous minerals excluding preparations for the treatment of textiles, leather, hides and furskins
Heat exchangers	Mg		28251130 Heat exchange units 24453025 Magnesium and articles thereof (excluding waste and scrap), n.e.c.
Powertrain			
Fuel cells	**Pt, Pd, REE, Co**	**not included**	
Hybrids	**REE**	**Permanent magnets covered by Energy**	
Energy storage	**Li, Zu, Ta, Co**	**Rechargeable batteries**	**27201100 Primary cells and primary batteries** **27201200 Parts of primary cells and primary batteries (excluding battery carbons, for rechargeable batteries)**
Energy efficient			
Advanced cooling technologies	**REE**		**28131165 Fuel, lubricating or cooling-medium pumps for internal combustion engines**
New illuminants	**REE, In, Ga**	**LEDs, LCDs, OLED covered by**	
Emission prevention			
Emission purification	**Ag, REE**		**20136500 Compounds of rare-earth metals, of yttrium or of scandium or mixtures of these metals**

In this section vehicles that are not used for personal transports are analysed. Heavy vehicles are defined as vehicles with diesel engines > 2500 cm^3 or goods vehicles with a gross vehicle weight > 5 tonnes. Heavy vehicles have more or less the same CRM dependence as automobiles with some minor changes related to energy storage, cooling or exhaust after-treatment which is of much larger scale.

The composition of a heavy vehicle is presented in Table 9. The first part of the table is the same as for the automobile. At the end of the table some applications has been added that are unique for the heavy vehicle. Energy storage like lithium ion batteries, zinc-air batteries or ultra-capacitor add Li, Co, Zn and Ta to the list of CRMs. Advanced exhaust after-treatment adds Ag to the list.

4.3.2 Analysis of CRM-related heavy vehicle market and supply chain

Economics

Heavy vehicle market

Roughly half of the 7.6 million heavy vehicles produced worldwide are produced in China (OICA 2013) The European Union (EU27) produces roughly 3% of the world's heavy vehicles (2013). However, European companies have 58% of the market shares globally but most production is situated outside Europe.

Position of EU in supply chain and main actors

The supply chain of the heavy vehicle consists of six main steps. In Figure 10 the supply chain of heavy vehicles is presented. The chain is focused on the heavy vehicle itself.

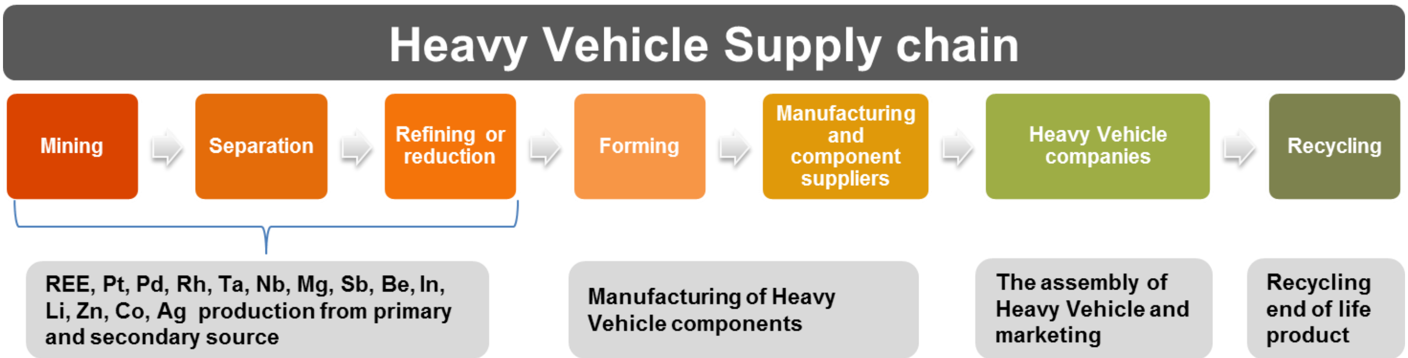

Figure 10: Heavy vehicle supply chain.

Jobs involved in EU

Based on major European truck manufacturer's structural business statistics (Daimler 2012, The Volvo Group 2012), the heavy vehicle sector employed about 73,400 people in 2012 within the EU.

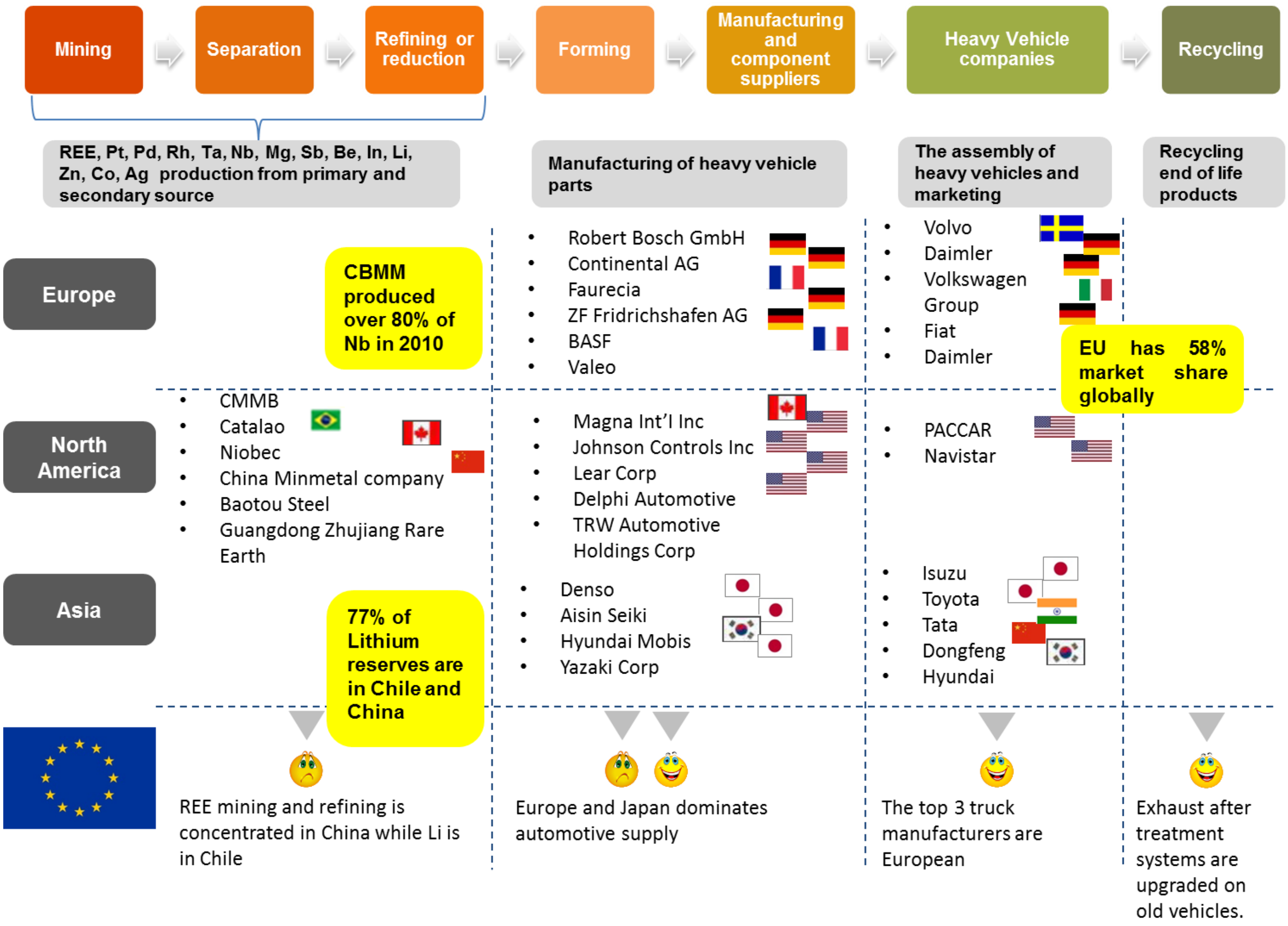

Figure 11: A summary of companies in heavy vehicle's supply chain.

EUROSTAT data interpretation

The quantitative supply chain analysis was carried out using data from Europe's PRODCOM database. The data from PRODCOM has been applied to produce supply chain illustrations showing which parts of the vehicle have the highest produced values in the EU.

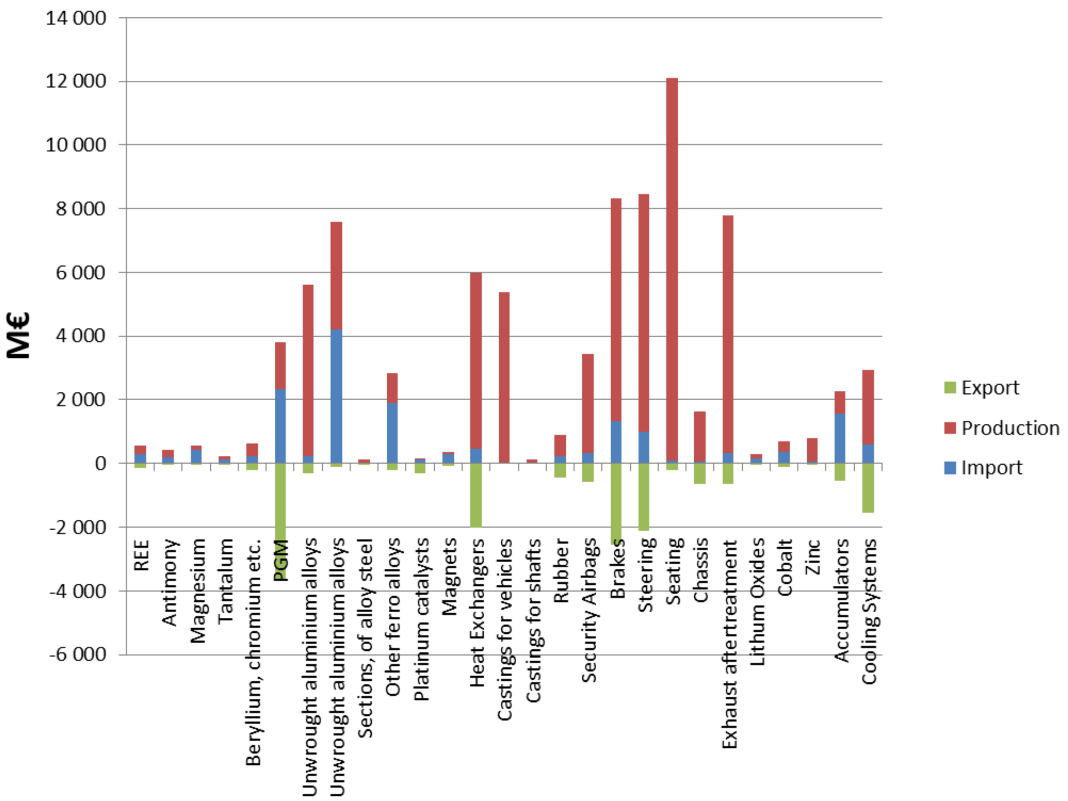

Figure 12: Relationship between production, import and export values for heavy vehicle components and materials in Europe 2012. Note the values for components and materials present the whole industry, not only the share used in heavy vehicles.

Criticality

Essentiality of the role of CRM

Larger energy needs on board heavy vehicles make lithium a significant metal in the heavy truck energy storage value chain. Lithium is essential for the lithium and lithium ion batteries. In addition lithium cobalt oxide is widely used in lithium ion batteries, making cobalt essential to the battery manufacturing. Li-ion and Zinc-air batteries have high energy density and have few alternatives.

The use of CRMs in heavy vehicles is very similar to that in regular automobiles. This means that the use of CRMs in catalytic converters, high strength steel, electronics and in permanent magnets in electrical control units are essential also to heavy vehicles.

How will the vulnerability of the application evolve?

According to recent studies (Kar 2013), the future overall markets for heavy vehicles do not seem very vulnerable at least in the short and medium run. In the long term, the development of new technologies and products, and the possible saturation of some market sectors, might have effects on markets. The vulnerability of the heavy vehicles manufacturing depends on the accessibility of the critical raw materials essential for the product. For example, limited access to heavy vehicle batteries would impact European heavy vehicle manufacturing, because of the small volume of actual battery producers located in Europe. However there is nothing that indicates that this is a risk at the moment (Gruber, P. W. et al. 2011).

Available substitutes

Although technological improvements will presumably lead towards resource-efficiency in the future, the global consumption of critical raw materials will increase because of the demand for heavy vehicles which constitute the backbone of inland logistics. A concern about sufficiency of these materials has led to attempts at developing substitutes. Most of these substitutes are still at the research stage, but some are already in use. Substitution for lithium compounds is possible in batteries: calcium, magnesium, mercury, and zinc can be used as anode materials. Tantalum can be substituted in electronic capacitors by aluminium and ceramics but usually with less efficiency. In applications like lithium-ion batteries, substitution with cobalt would result in a loss in battery performance. Potential substitutes are iron-phosphorous, manganese, nickel-cobalt-aluminium or nickel-cobalt-manganese.

Impact on European policies in case of supply disruption

The EU has a strong commitment and goal to heavy vehicle emission regulation and any case of supply disruption regarding environmentally friendly technology on-board heavy vehicle could compromise these targets.

Innovation

Substitution activities already ongoing

Some of the substitution strategies are related to the shift toward new value chains that are not dependent – or less dependent – on CRMs. One example for heavy vehicles is the shift toward natural gas as a fuel. By replacing diesel, it allows a lower cost, and lower needs for CRM in the emissions after-treatment steps compared to diesel.

4.3.3 Heavy vehicle – business summary

A summary of business analysis is presented in Table 10.

Table 10: A qualitative summary of the heavy vehicle supply chain analysis.

Criteria	Sub-criteria	Required input
economic	Economic value of application or area	• The market revenue of heavy vehicle manufacturing in Europe was €33 billion in 2012.
	Position of EU in entire supply chain	**Exhaust after treatment:** • European emissions standards for trucks (in g/kWh engine output) are used worldwide and catalytic converters production and scrubbers are dominated by European companies. **Heavy vehicle:** • The market share of European truck manufacturers is about 58%.
	Jobs involved in the EU	• About 73,400 persons are employed in 2012 in manufacturing trucks in Europe. • About 383,000 persons are employed by the heavy vehicle sector in Europe in 2012.
criticality	How essential is the role of the critical material in the application?	• Platinum is essential in catalytic converter production. • Mg is alloyed with aluminium, zinc, copper, nickel, lead, zirconium and other metals used in the automotive industry. Mg production in 2009 was 30,190,000 tonne mainly from China (56.1%), Turkey (12.0%) and Russia (7%). • Ta, Co, Li, Zn are essential for the functionality of on board energy storage systems
	How will the vulnerability of the application develop over time?(as a result of RM and market developments)	• Shortages in supply and price increase of platinum and palladium are expected. • The market for truck manufacturing in Europe is shifting to the east where the growth is higher and manufacturing costs lower. • The transition to cleaner fuels (H_2) and powertrains (EV, hybrid, FCV) is adding constraints and can lead to more CRM in the heavy vehicle sector.
	Available substitutes?	• Palladium instead of platinum. • Silver alloys instead of palladium.
environme ntal	Impact on European policies in case of disruption	• Disruption of catalytic converter material or higher price for exhaust after treatments system could favour alternative powertrains like Hybrid where lower tail emissions could be achieved without “end-of-pipe” technologies.
Innovation	Substitution activities already on-going? What is the status of that research?	• Having more composites and polymer onboard instead of metals and alloy is a trend that could grow in the future. • Recycling and minimizing use of REEs and PGMs. Replacing Pt by Pd when possible is also under scrutiny.

Principle of substitution: is substitution conceivable?	• The extent of how metal and alloys are substituted by polymers and composites is unclear
Potential for Europe	• The leading European air quality standards as well as the positioning of European companies in the exhaust after treatments systems are clear opportunities to export and develop the technology abroad.

4.4 Aeroplanes

4.4.1 Aeroplanes and CRM dependence

Aeroplanes studied here are jet engine or propeller powered fixed-wing aircraft that are propelled forward by thrust from a jet engine or propeller. In Table 11 the composition of aeroplanes is presented.

Table 11: Structural composition of an aeroplane.

	CRM Content	Comments	Identified PRODCOM categories
Aeroplane			30303200 Aeroplanes and other aircraft of an unladen weight <= 2000 kg, for civil use 30303300 Aeroplanes and other aircraft of an unladen weight > 2000 kg, but <= 15000 kg, for civil use 30303400 Aeroplanes and other aircraft of an unladen weight > 15 000 kg, for civil use
Navigation and control Electronics	Sb, Ge		26511150 Instruments and appliances for aeronautical or space navigation (excluding compasses) 26512050 Radio navigational aid apparatus (including radio beacons and radio buoys, receivers, radio compasses equipped with multiple aerials or with a directional frame aerial) 26518100 Parts of radar apparatus and radio navigational aid apparatus
Infotainment	Many	A modern airplane for passenger transport contains hundreds of displays, ICT	
Body	Mg	Fuselage normally made from the alloys Al6000 or Al 7000 containing about 1% Mg, in the latest generation of aircraft e.g. New Airbus models and Boeing 787 the Al alloys are replaced by carbon fibre composits in many applications	Included in Mechanical components, see below.
Mechanical components	Mg	High strength Al-alloys e.g. Al6000-Al7000 alloys	30301600 Parts of turbo-jets or turbo-propellers, for use in civil aircraft 30305090 Parts for all types of aircraft excluding propellers, rotors, under carriages, for civil use
Brake system	Gd, Rh, Pd		29323020 Brakes and servo-brakes and their parts (excluding unmounted linings or pads)
anti-lock brake systems	Be		
Electrical Pumps	Pr, Sm and others		28121320 Hydraulic pumps (radial piston) 28121350 Hydraulic pumps (gear) 28121380 Hydraulic pumps (vane) 28121530 Hydraulic pumps (axial piston)
Engine			30301200 Turbo-jets and turbo-propellers, for civil use 30301300 Reaction engines, for civil use (including ramjets, pulse jets and rocket engines) (excluding turbojets, guided missiles incorporating power units)
High pressure turbine blade Ni based superalloy	W, Ta,Ru		
Low pressure turbine blade made from titanium-al	Nb	e.g. Alloy Ti6Al4V used where possible due to lower weight compared to above	
Combustor	Y		
Components used in road transport e.g. leds, lights		covered in ICT report	
Flame retardant	Sb		

- Two critical raw materials antimony and germanium are used in the navigation and electronic components of the plane. Critical materials are also essential in the fuselage manufacturing.
- Critical raw materials are also used in the jet engine the brake system and other mechanical components.
- Beryllium (Be) because of its hardness, high melting point, and exceptional ability to dissipate heat is used in aeroplanes brakes.
- Because of its light-weight (two-thirds the density of aluminium) the use of magnesium alloys in aerospace is increasing, mostly driven by the increasing importance of fuel economy.
- Tantalum (Ta) is used to make superalloys with high melting points, which are very strong and have good ductility.
- The number of aeroplanes produced per year is 2164 (Barr Group Aerospace 2012).
- The global fleet of airliners in 2013 is 17,739 and is expected to grow to 36556 by 2032 of which 29226 will be new aircrafts (Airbus 2013).
- The demand for aeroplanes between 2013 and 2032 will mostly be for single aisle aeroplanes (Boeing 2013).
- Based on the scenarios from Boeing and Airbus, the consumption of Be for aeroplane applications could go from 30 tonne per year in 2012 to 52 tonnes in 2032.

Also materials that are not defined as CRMs by the EU are critical for the aerospace industry, such as carbon fibre and titanium. Carbon fibre is considered critical since there are no producers within the EU and there are only a few producers worldwide. Titanium alloys are used for the plane body and as titanium prices has gone up the industry is looking for substitutions, either with other alloys or composite materials (Fani, M. 2014).

4.4.2 Analysis of CRM-related aeroplanes market and supply chain

Economics

Most aeroplanes are produced in the US. In 2012 1,518 aircrafts where produced in the US and 2,164 globally. Revenues from global aeroplane production were €13.81 billion in 2012 (Barr Group Aerospace 2012).

Propeller aeroplane market

Propeller aeroplanes make use of piston engines or jet engines to turn a propeller to create thrust. The propeller aeroplane market is evolving with old propeller aircrafts being replaced and an increased interest in this segment due to higher fuel prices. A propeller based aeroplane usually uses less fuel per passenger. The number of propeller aeroplanes sold globally is much higher than jet aeroplanes. In 2012, 1,256 propeller aeroplanes where sold vs. 672 jet aeroplanes (Aeroweb, 2014). Propeller aeroplanes represent 69% of the market in units sold.

Jet aeroplane market

Jet aircrafts generally fly faster and at higher altitude than propeller aeroplanes. The jet aeroplanes market is dominated by Airbus and Boeing.

The jet aeroplane market is usually described as the general aeroplane market since most airlines are using jet aeroplanes. The market is expected to grow at 5% annually in terms of passenger number for the next 20 years (Boeing 2013). The long-term demand forecast from Boeing is some 35,280 new aeroplanes by 2030, with a total value of €3.9 trillion. Airbus sees forecast somewhat down on Boeing’s figure with 29,226 new aeroplanes by 2032.

Position of EU in supply chain and main actors

The supply chain of aeroplanes consists of six steps. In addition, the supply chain can include parallel streams for different components including CRM. In Figure 17 **Fel! Hittar inte referenskälla.**the supply chain of aeroplanes is presented. The supply chain is focused on aeroplanes components that include CRM.

Figure 13: Aeroplane supply chain.

The supply chain can be roughly divided into four different stages. The first stage is raw material production from primary or secondary sources. The material can be in the form of a pure metal powder or an alloy. The second stage is the manufacturing of aeroplane parts. The third stage of the supply chain is the assembly of the components to produce an aeroplane that can be marketed and sold. The final stage of the supply chain is the recycling of end of life products.

A summary of the main actors in the aeroplane supply chain is presented in Figure 18.**Fel! Hittar inte referenskälla.**

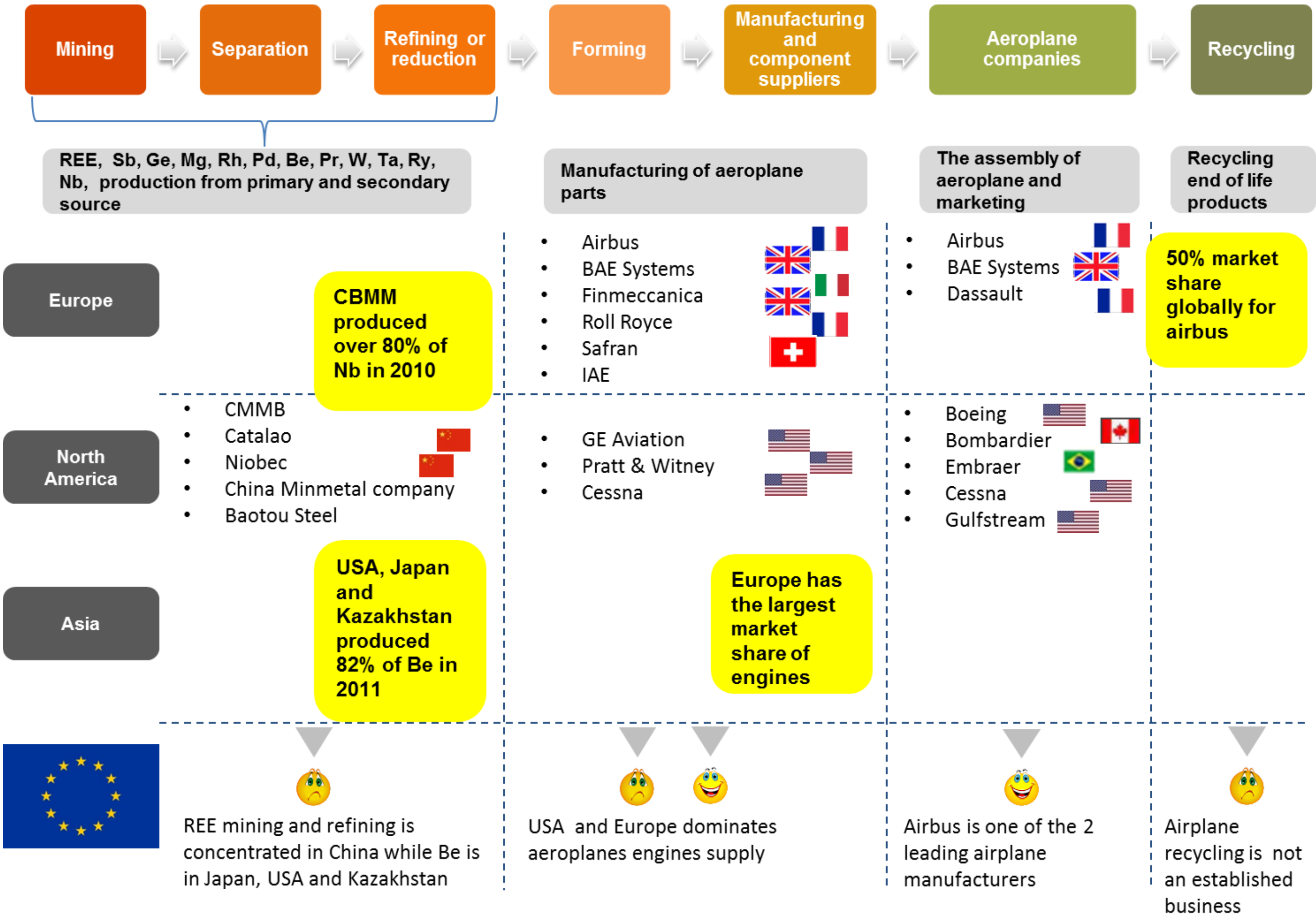

Figure 14: A summary of main actors in aeroplane supply chain.

<u>Jobs involved in EU</u>

Airbus, by far the biggest aeroplane manufacturer in Europe, employs around 63,000 people at sixteen sites in four countries: France, Germany, Spain and the United Kingdom. This does not include jet engine and aeroplane subcomponent manufacture. The jet engines account for up to a third of the value of a new jet.

<u>EUROSTAT data interpretation</u>

The quantitative supply chain analysis was carried out using data from Europe's PRODCOM database. More detailed information on the data and application composition can be found in Figure 19. The data from PRODCOM has also been applied to produce a supply chain illustration where the size of the boxes are proportional to the produced value in Europe, see Figure 20.

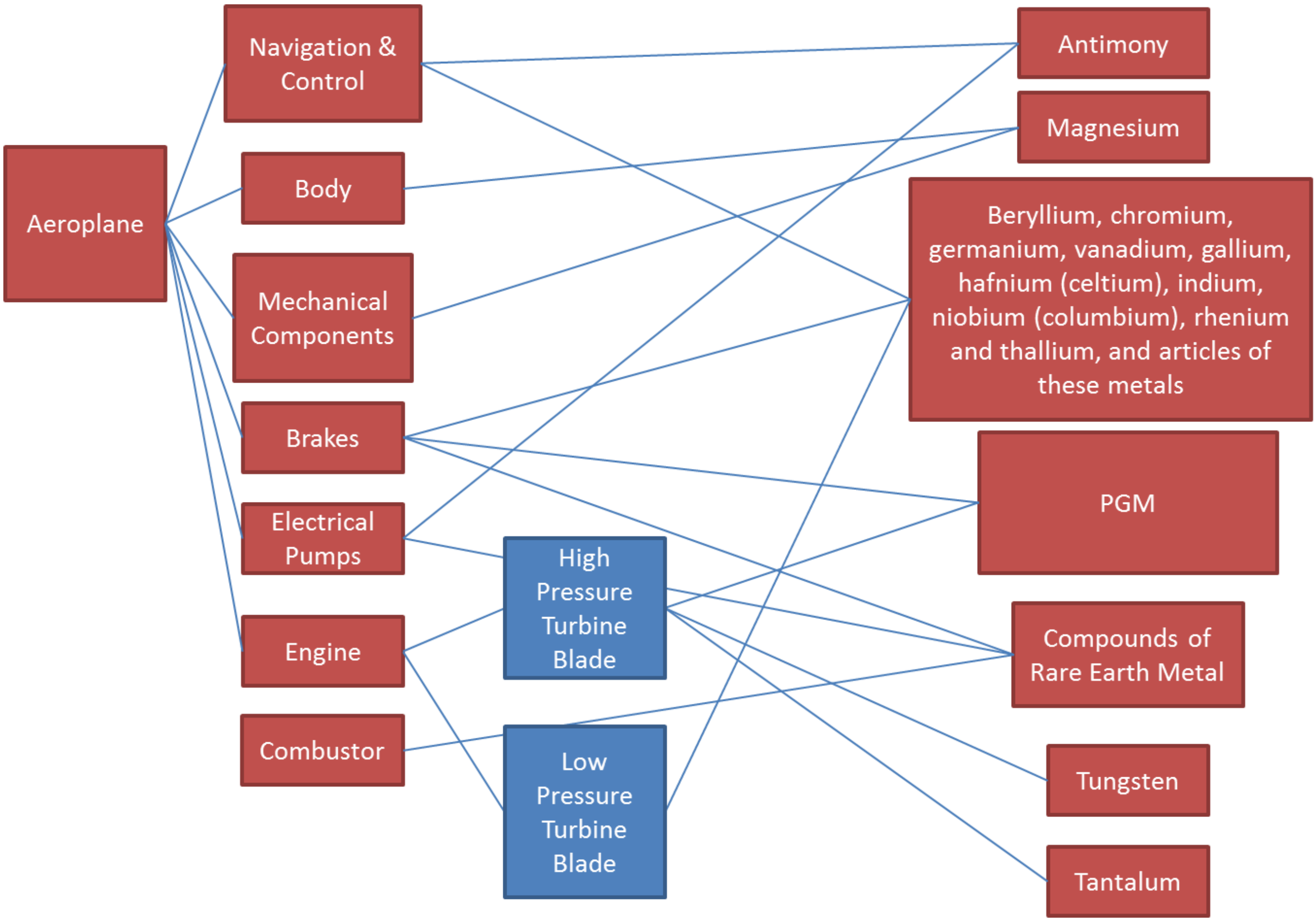

Figure 15 EU production of aeroplane systems and related (sub)-components and materials. (Sub)-components in blue boxes have no corresponding PRODCOM group and therefore no statistically defined value and are included for completeness.

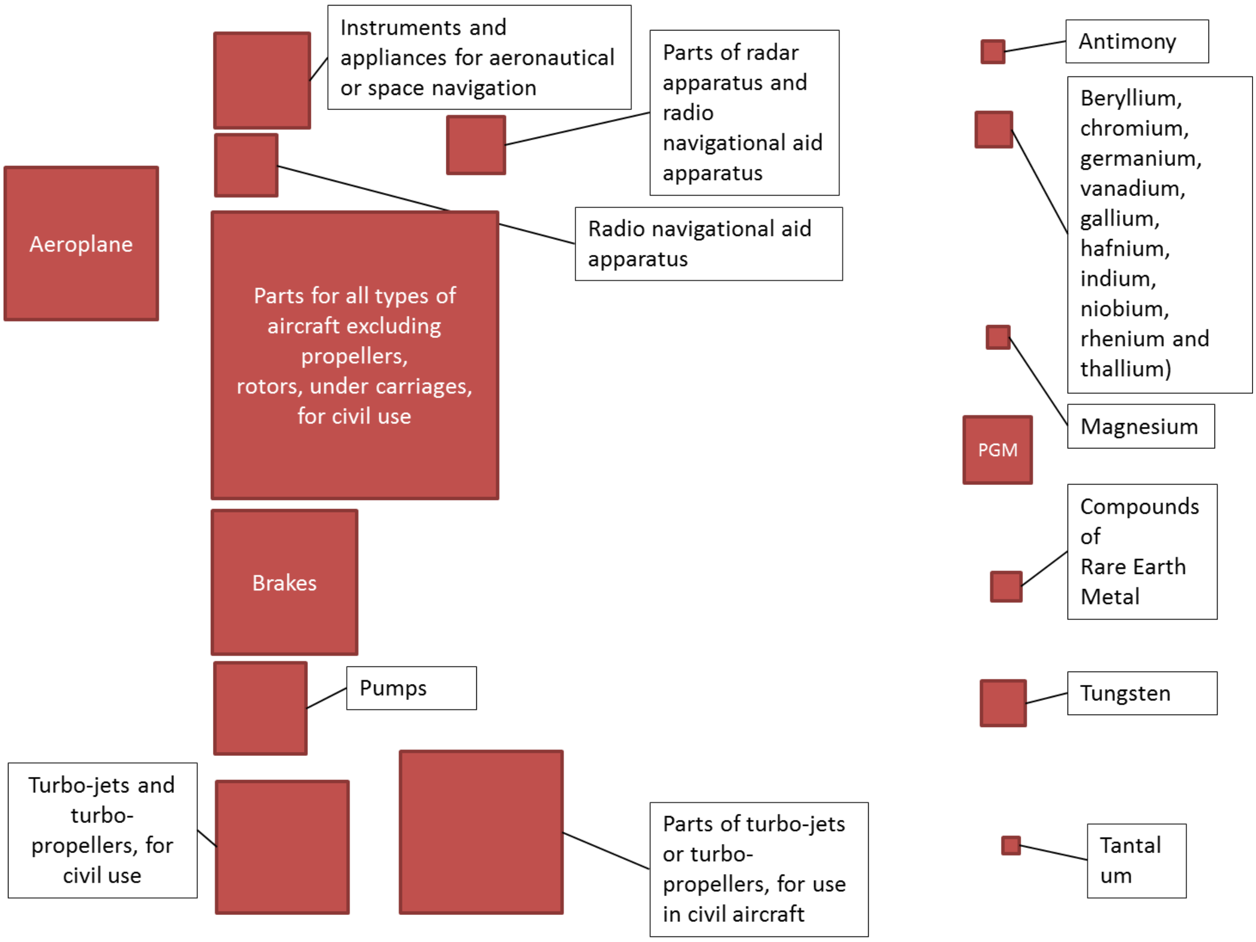

Figure 16 EU production of aeroplane systems and related (sub)-components and materials. The boxes are scaled in proportion to the produced value in EU 27.

European production in the supply chain of aeroplanes exists both on component and end application level. With companies like Airbus, BAE Systems, Dassault Aviation or Thales group, Europe has a strong aeronautics manufacturing sector. The largest producing country is France where most of airbus assemblies take place. Airbus has also several factories in Germany, the UK and Spain. The balance between production, import and export in the supply chain of aeroplanes is presented in Figure 21.

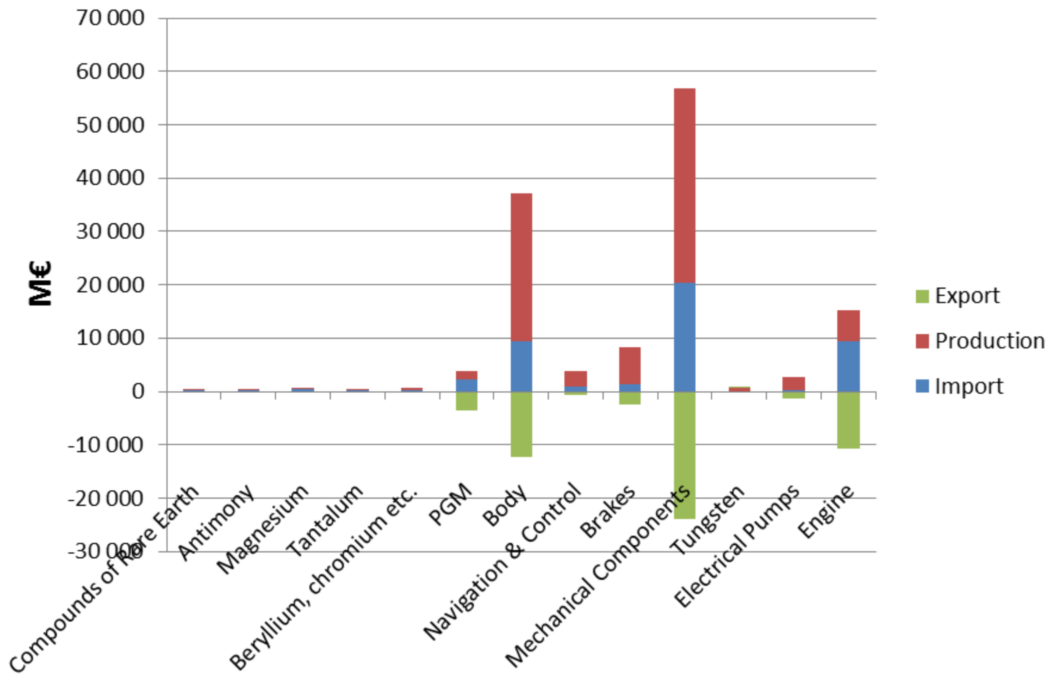

Figure 17: Relationship between production, import and export values for aeroplanes, aeroplane components and materials in Europe 2012. Note the values for components and materials present the whole industry, not the share which is only used in aeroplanes

The sum of **Fel! Hittar inte referenskälla.**production and import, which are presented on the positive side of the x-axis, represent the cumulative value of articles which are within Europe. Consequently, the value of export is on the negative side and expresses the value of articles which leaves Europe

Figure 21**Fel! Hittar inte referenskälla.** shows that production dominates the trade balance for aeroplanes. In addition, the high export value and lower import value indicates high consumption of European products outside Europe.

Criticality

Essentiality of the role of CRM and available substitutes

The role of critical raw materials is essential in the aeroplane production process. The UK Environment Agency categorized beryllium, niobium and magnesium as critical raw material for aircraft production (UK Environment Agency 2011). Whereas niobium substitutes exist and can perform somehow satisfying, beryllium and magnesium substitutes performs poorly. In the case of magnesium, it is almost impossible to replace.

How will the vulnerability of the application develop over time?

Based on previous estimates, the future overall markets for aeroplanes products do not seem very vulnerable at least in the short and medium term.

Available substitutes

There are some available substitutes or aeroplane critical raw materials. However they do not always perform as well as the original and research is on-going to find optimal compositions. For instance, the cost of beryllium is high compared to other materials and it is used mostly in applications where its property is essential and is often not substitutable. Health safety and environment (HSE) considerations can push toward substitution strategies and because beryllium is toxic (Lupton 2003), even though substitute may underperform, they are used in some applications. Cu-Ni-Sn is a replacement for Cu-Be already implemented at Boeing (Boeing 2010).

Environmental

Impact on European policies in case of disruption

In case of aeroplane production disruption because of CRM, the EU is likely to take extreme measures and/or implement policies to back Airbus versus Boeing (BBC News 2005). In the EU, GHG emissions from aviation increased 87% between 1990 and 2006 (EU Commission 2006). A new fleet of aeroplanes which are more fuel efficient could help reduce the climate impact of EU air transport. The Airbus A320neo, for instance, is predicted to result in 15% less fuel consumption and a reduction of nitrogen oxide (NOx) emissions by at least 10% compared to the A320 series (Airbus 2014). A disruption in aeroplane production due to CRM issues could delay the replacement of old aeroplanes by new ones like the A320neo in the EU.

Innovation

Substitution activities already on-going

Carbon fibre composites have higher strength-to-weight ratios than traditional aircraft materials, and help make lighter aircrafts. Composites are used on fuselage, wings, tail, doors, and interior. They help by saving on expensive lightweight metals like magnesium. The Boeing 787 Dreamliner already uses 50% structural composite by weight, the Airbus A350 uses 53% composites (Airbus 2013), the V-22 Osprey 50% (Dea et al 2001) and the C-17 Globemaster III use 6% (Boeing 1995).

4.4.3 Aeroplane – business summary

A summary of business analysis is presented in Table 12.

Table 12: A qualitative summary of the aeroplane supply chain analysis.

Dimension	Criterion	Required input
economic	Economic value of application or area	• In 2012, the size of the global aircraft market was around €406 billion. New aircraft deliveries will reach 12,800 units, generating over €458 billion in sales revenue over the next 20 years. • The production of all type of aeroplanes in Europe was approximately €7.8 billion in 2012 (Eurostat).
	Position of EU in entire supply chain	• Aeroplane production in Europe is leading compared to Asia. • The manufacturers of aeroplanes are well represented in Europe with Airbus having about 50% market share over large commercial aircrafts.
	Jobs involved in the EU	• Direct employment in the European aeronautic manufacturing industry is 466,900 people (2008)
criticality	Essentiality of the role of CRM	• Very essential, especially since aeroplane production is located inside Europe and thus the European link to the CRM essentiality is direct.
	How will the vulnerability of the application evolve (as a result of RM and market developments)?	• The future overall markets for aeroplanes do not seem very vulnerable at least in the short and medium term. Availability of beryllium may form a bottleneck for European industry. The US has reopened Be production in Ohio to ensure security of supply as advised by the Department of Defence.
	Available substitutes?	• Substituting niobium is somehow possible. For beryllium or magnesium substitution it is much harder as substitutes are really underperforming and undermining applications.
environment al	Impact on European policies in case of supply disruption?	• Loss in competitiveness
innovation	Substitution activities already ongoing? What is the status of that research?	• The largest trend in the aeroplane industry is recycling. Today only 30% of an aeroplane (by weight) is recycled when there is a potential for a valorisation of 85% of the weight, with reuse and recycling above 70%. • Substitutions activities are rare and currently substitution research exist like substituting beryllium by certain metal matrix or organic composites, high-strength grades of aluminium, pyrolytic graphite, silicon carbide, steel, or titanium.

Principle of substitution: is substitution conceivable?	• The cost of substitution is as of today too high. Recycling is more conceivable since it is not implemented fully yet. Substitution may come later on when recycling rate have reached a plateau.
Opportunity for Europe	• Europe is a leader in aeroplanes manufacturing and recycling as well as substitution and new material use (like composites) represent a very big opportunity to increase Europe competitiveness and technology export.

5 Conclusion

The transport sector is an evolving industry segment, in which both production and market is strongly shifting toward Asia. However, the production of some applications does also exist in Europe. Based on the supply chain study carried out for three assembled vehicles it can be concluded that the transport industry in Europe is concentrated mainly to end product/application production.

Automotive is one of the key market areas in transport. The sector of automobile manufacturing employed around 2.3 million people in Europe in 2012. Three European car companies are in the top ten producers and several Japanese companies, such as Toyota, have manufacturing plants in Europe. The market segment in Europe is highly competitive and is driven by high pricing pressure, hence the success of low cost sub-brands like Skoda or Dacia. Based on data from Eurostat, production in Europe is distributed over the whole supply chain but clearly concentrated to the later steps of the chain.

One of the main CRM dependencies is the use of platinum and palladium in catalytic converters. Leading European auto producers do not have catalytic converter production of their own. Availability of raw materials could be a potential CRM related bottleneck and since production of the catalytic converters are mainly produced outside the EU and not by the European automotive companies themselves, chances to influence availability of catalytic converters in case of shortage of raw materials might be limited. Both platinum and palladium production are concentrated in South Africa and Russia. In terms of substitution of the platinum in cars, the on-going shift is toward palladium which is less expensive and with more diverse production areas, however, substituting a CRM with another does not reduce CRM dependency. There are at the moment no other substitutions for the CRMs used as catalysts in catalytic converters, the same is true for exhaust after treatment applications that to replace catalytic converters.

Different types of high strength steels are of great importance for automobiles due to safety requirements. Niobium alloyed steel is mainly used and, in some parts of the car, tantalum alloyed steel. Any material of function used to replace those safety functions must meet the same requirements as the steel used today. Composites may replace some of those steel parts in the future, as long as that does not give an impairment to the performance of the material.

Electronics play a more and more central role in cars. Basic vehicles have at least around 30 electronic control units (ECUs) while luxury cars might have as many as 100 (New York Times, 2010). This renders car functioning highly dependent on electronics, and therefore CRMs. A few systems that are dependent on ECUs in a car are fuel injection control, cooling systems, anti-lock breaking systems, air bags and adaptive cruise control systems. Because of the great use of ICT products in general and the large amount of CRMs used in those products ICT was the subject of a parallel report by the CRM_InnoNet consortium (Bachér et al., 2013).

Another application that has not been examined in detail in this report is the use of permanent magnets containing rare earth elements. However, permanent magnets used in electrical motors of varying size, are crucial for modern cars. The supply chain of permanent magnets is treated in more detail in the CRM_InnoNet report on energy applications using CRM (Brunot et al. 2013).

Platinum and other platinum group metals are recycled to some extent. But this is an exception when it comes to recycling critical raw materials from cars. No dedicated procedures or processes for recovering and recycling the content of gold, neodymium, tantalum and niobium of components or material fractions from end of life vehicles (ELV) can be observed in the current Swedish ELV system. Directives on recycling from end of life vehicles in the EU are not focused on critical raw materials but more on e.g. plastic parts. But recycling of rare metals might be one way to address short-term supply risks and long-term scarcity issues related to increased global demand of scarce metals (Andersson, M., et al. 2014).

Heavy vehicles are the backbone of inland logistics and are an important indicator of economic development. Due to a strong Asian demand, the heavy vehicle segment will continue to grow. In 2012 the general heavy vehicle market revenue size in Europe was around €33 billion and the manufacturing of heavy vehicles employed around 73,400 people in 2012. The top three heavy vehicle manufacturers are all European and there is also a large number of SMEs focused on innovative heavy vehicles applications. It has been estimated that the market growth for heavy vehicle will increase 5.5% per year from 2012 to 2022. Examining the data from Eurostat it can be noticed that heavy truck production in Europe is focussed on end production.

Small amounts of critical raw materials (e.g. Ta, Co) are essential for the functionality of on board energy storage systems. As for substitution, new materials using aluminium or ceramics are under development; however it will take time before all CRMs in different energy systems – batteries or ultra-capacitor - are replaced.

For heavy vehicles, high strength steel and super alloys are used for the same reason as for automobiles. But the pressure to constantly increase safety is not quite as strong in this sector as for the car sector. Heavy vehicles are, in the same way as cars, highly dependent on electronics and electric motors, using a large amount of CRMs. These applications are addressed in CRM_InnoNet reports on ICT and electronics (Bachér et al., 2013) and energy (Brunot et al. 2013).

Aeroplanes enable the global transport of people in the minimum amount of time. In 2012 the world production of aeroplanes was approximately worth €13.8 billion and the manufacturing of Airbus aeroplanes employed around 56,411 people in 2010. The demand for aeroplanes is expected to grow due to emergence of a world middle class and an increase in tourism destinations. Based on the data from Eurostat, the production value in Europe increased when moving along the supply chain towards the whole aeroplane.

The main CRMs used in the production are beryllium, niobium and magnesium. About 11% of beryllium production is consumed aerospace applications. Aluminium alloys are of great importance for both road vehicles and aeroplanes. The CRM used in those alloys is magnesium; there are trends in the aerospace industry toward higher magnesium content in the alloys used in the plane body. This trend could lead to magnesium supply becoming more critical for the industry in the future.

Also materials that are not defined as CRMs by the EU 2010 report (European commission, 2010) are critical for the aerospace industry, such as carbon fibre and titanium. Carbon fibre is considered critical since there is no producer within the EU and there are only a few producers worldwide. Titanium alloys are used for the plane body and as titanium prices have gone up the industry is looking for substitutions, either with other alloys or composite materials.

Action is taken in the aerospace industry to reduce the dependency of CRMs for the plane body, for example replacing alloys with composites.

For aeroplanes the use of superalloys is crucial for the jet engines, where a high strength material that can stand a high temperature load is needed. Those alloys are niobium based but use additional materials such as tungsten, tantalum or ruthenium. Ruthenium has been replaced to a large extent due to high prices.

Aeroplanes also have a large amount of electronics and electric motors that are crucial for the operation of the plane. These applications are addressed in the reports on ICT and Energy.

Appendix 1 (methodology)

Terms and definitions

Definitions related to analysis methodology are presented below:

Centralized data source

The centralized data sources include statistical databases, such as: PRODCOM (Eurostat database providing statistics on the production of manufactured goods), SBS (Structural Business Statistics), BACI/COMTRADE (International Trade Database/The United Nations Commodity Trade Statistics Database, EXIOBASE (global, Multi-regional Environmentally Extended Supply and Use / Input Output database by the University of Leiden).

Application

The special use or purpose to which a technology or product is needed. For instance, “data storage” is an application.

User sector

In this report the user sectors are: energy, ICT and electronics and transport (aerospace and automotive)

PRODCOM sector

The sectors defined in PRODCOM database, for example “Manufacture of electrical equipment”, “Manufacture of machinery and equipment”

Product group

When the centralized data sources are used in the statistical analysis, “product group” defines what can be considered an application/product/technology. For instance, if “data storage” is an application (see definition above), the corresponding product group classification is “Digital Processing Units Whether Or Not Presented With The Rest Of The System Which May Contain Storage Units” (and other groups that have similar elaborate descriptions).

Statistical analysis

The statistical analysis of supply chains contains:

- A majority of raw materials and intermediate products related to the product group and containing CRM;
- Production, import and export of raw materials and intermediates expressed in €. If relevant volumes in tons of raw materials are added;
- A maximum of 3 EU countries that supply the largest share (in €) of parts of the value chain.

Business analysis

A partly quantitative, partly qualitative report and a summary table as addition to statistical value chain analysis (see above). It provides essential information for prioritisation of the applications (see Table 14) and insights on the value chain analysis in the CRM_InnoNet project. The report lists individual stakeholders (companies) if feasible.

Introduction

The aim of this work is to create more understanding about the relevance of critical raw materials (CRM)[1] for the European economy and to give indications of which applications could be under threat. On account

[1] The starting point in this work was the list of 14 Critical Raw Materials highlighted in the EC’s report: Critical Raw Materials for the EU. Report of the Ad-hoc Working Group on defining critical raw materials. Version of 30 July 2010.

of economic importance the following user sectors have been selected for analysis: Energy, ICT and electronics and transport with specific emphasis on aero and automotive transport. Selected key applications from each sector were assessed by examination of the 'CRM supply chain' for each application. When starting the work, the objective was to make a value chain analysis of selected applications. However it was found that using the data sources available, it was not possible to get information on the value addition of components used in the end applications which is required for a full value chain analysis. Therefore it was chosen to rather make an analysis of the supply chains as a way to get at least partial information on the value chain.

This 'CRM supply chain analysis' examined the economic importance, CRM availability and strategic relevance over each stage in the production of the selected application. In addition, analysis of current risk provision strategies and opportunities for industries was completed. The full assessment methodology is presented in the summary report.

The value chain analysis is part of the project CRM_InnoNet (Substitution of Critical Raw Materials). The data produced will (together with the additional data produced in the bottom-up-analysis of the CRM-landscape[2]) be used in prioritisation of the applications for elaboration of a roadmap for the substitution of Critical Raw Materials.

Supply chain analysis methodology

In developing a methodology for analysing the value chains of applications the following factors were considered to be important:

- Economic relevance to Europe.
  The focus was in understanding where in the supply chains of applications (Figure 18) the value for Europe is produced, creating basis for assessment of the economic vulnerability of the applications. In previous studies, economic aspects have been discussed only superficially. The information needed was compiled by analysing the supply chains for the following quantities: production in EU countries, import to and export from these countries.

- Transparency and transferability.
  In all three user sectors critical raw materials are used in a wide variety of different applications. In order to produce reliable and comparable results, the same analysis methodology needs to be applicable to all three user sectors and common data sources need to be used. Therefore the quantitative economic analysis was performed using statistical data sources.

- CRM relevance.
  Most of the applications are composed of numerous components or intermediate products, making the supply chains of the applications complex. As this study aims to identify bottlenecks arising from lack of availability of critical materials, only the parts of the value chain containing critical raw materials were analysed.

In addition to analysis of current economic relevance, it is important to point out how the vulnerability of the applications is expected to develop in the future, and how the potential disruption would affect Europe's ability to meet strategic targets. It is not possible to assess such factors on the basis of current market data so a qualitative approach using market and sector reports was adopted.

[2] CRM_InnoNet, Deliverable report D3.3. Raw Material Profiles. September 2013

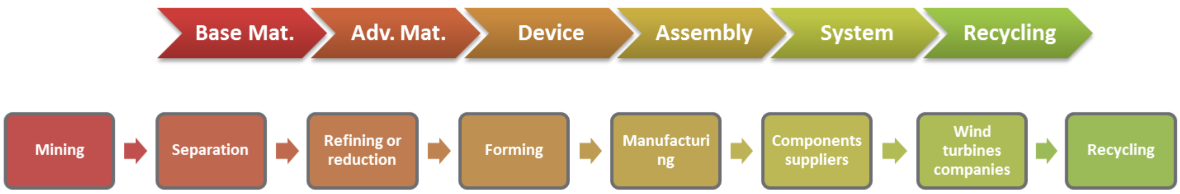

Figure 18: Main stages of a supply chain. Supply chain of wind turbines is presented as an example

In order to highlight the most important applications for the European economy, screening was required to reduce the number of applications to a manageable number for in-depth study via a supply chain analysis. Therefore a two phase approach was followed:

Phase 1: screening

The first phase was the identification of suitable applications to progress to full supply chain analysis from a complete list of applications relevant to a particular user sector. The applications were screened by considering three criteria to assess CRM dependency and economic importance to Europe.

Phase 2: supply chain analysis

The second phase was the full CRM supply chain analysis of the selected applications. The full analysis approach was composed of a statistical analysis (statistical analysis) and examination of supporting market and technical qualitative and quantitative data by experts (business analysis).

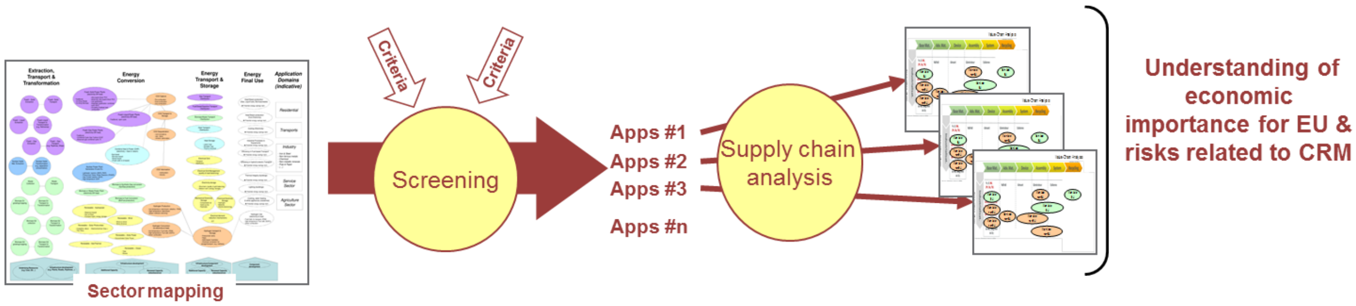

Figure 19: Approach to selection of applications for supply chain analysis.

Because the selection of applications for supply chain analysis and the implementation of the analysis had to be made in a uniform and transparent way, the same analysis methodology was applied for all three user sectors. The step by step description of the analysis methodology is presented in the following. The definitions of the terms used can be found on at the start of Appendix 1.

Description of the methodology

Phase 1: screening

Step	Description
1	The scope of the user sector is defined and a 'long list' of relevant applications is created. (Applications with no CRM dependence or very small markets are not included).
2	The statistically defined product groups corresponding to the applications on the long list are defined using CPA (Statistical classification of products by activity) and HS (Harmonized Commodity Description and Coding System) classifications, and the products are analysed for EU share of production and EU consumption/use using centralised data bases (PRODCOM).
3	The most relevant applications are selected for full supply chain analysis by evaluation against three criteria: A. Are CRM used in the supply chain of the application? This has been pre-evaluated during step 1 and is verified here. B. Does the EU produce at least 25% of the value (x) that is consumed/used of this product within the EU? The value x = (EU production)/(EU production + import) is calculated using data extracted from the PRODCOM data base. C. In order to ensure that the biggest EU industries in the three user sectors are represented, the total size of EU production of the product should have at least a share of 0.2% in the total output of the representative PRODCOM sector. The limiting value has been determined so that for the smallest sector the threshold would be at least €500 million. Consequently for the largest sector the threshold is around €1,100 million. PRODCOM values are used in calculation. The order of magnitude of the European market for this product should be stated. In addition, in order to ensure the comparable complexity of products, it is recommended that the products should have minimum four and maximum twenty five supply chain entities.
Applications that meet the three criteria described above progress to phase two, full supply chain analysis.	

Phase 2: supply chain analysis

A 'structural composition' i.e. a list of the CRM containing components and materials in the product is produced (see Table 13).

Table 13: Excel table used for description of the structural composition of an application (Example: light-emitting diode).

Light emitting diode (LED)	CRM content	Comments
LED module		
LED		
Semiconductor die	In, Ga	
Phosphors	Ce, Y, Tb, Lu, Eu, Gd	
Electronics		
Printed circuit board		
Plating	Pd	Not very common to use Pd as plating, generally Ni/Cu and Au are used
Components		
Capacitors	Ta, Pd, Nb	
Resistors	Ta, Ru	
Semiconductors	Ga, Ge, In, Sb	
Transistors	Ga, Ge	
Connectors	Pd, Ru, Be	
Cables		

1. In order to enable statistical analysis, a list of comparable raw materials and intermediate products as defined by statistical classification (CPA and HS classification) is produced. This list represents most relevant parts of the supply chain attached to the application.

2. Quantitative and qualitative market/product information (such as sector reports, company reports, data from strategy consultants, interviews, etc.) is collected and used as input for the Business analysis part of the work. The aim of the business analysis is to complement the information produced by statistical analysis and to enable comparison between the centralized and other data sources. The topics to be discussed in the business analysis are presented in Table 14. The amount of jobs is collected from the statistical databases.

Table 14: The topics to be discussed in the business analysis report.

Dimensions	Sub-criteria
Economic	Economic added value of application in Europe Main actors in the supply chain
	Jobs involved in the EU (excluding indirect jobs)
Availability	Amount of CRMs involved
	Expected future market development
	CRM function
	Availability and status of substitutes
Strategic Relevance	Associated to EU policies for CRMs supply, or specific application development

3. Data from centralised sources is collected and analysed for every part of the statistically defined supply chain of the selected products. The following methodology is used:
   a) Total EU and EU country level production, export and import data is extracted from PRODCOM and BACI/COMTRADE data bases
   b) Using the statistical data, tables or graphs are produced summarising the following information for every part of the supply chain: Total EU production, import and export, 3 major EU producer countries, production and trade balance in these countries.
   c) The blanks in statistical data are filled using the general market data produced by Business supply chain analysis, if available.

4. For comparison and verification of the results, the statistical supply chain data is matched with specific market/product information and any potential discrepancies discussed.

5. The application specific results of the business analysis (the information presented in Table 14), and those of the analysis (graphical presentation of the EU production, export and import data) are reported. The interpretation of the results is discussed in sector specific reports (D1 – D3) and in Chapter 5 of summary report.

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