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Content

Preface

The Sustainable Consumption and Production Working Group of the Nordic Council of Ministers commissioned a study to create a picture of the supply chain of metals used in clean technology (cleantech) sectors of electric vehicles and solar panels. Cleantech was chosen as a focus point for the study because it is a rapidly growing sector and will face similar challenges related to metal use as, for example, electronics companies have for a longer period of time.

The study examines how Nordic cleantech companies are aware and acting on the challenges related to the lifecycle of metals and what are the potentials to minimise environmental impacts. The study results with recommendations and conclusions for Nordic cleantech companies on why they should and how they can pay more attention to their supply chain and improve sustainability. The study shows that to mitigate the potential problems related to Rare Earth Metals (REMs) and critical metals, companies will need to develop their knowhow and procurement processes.

Nordic countries have the responsibility to lead sustainable development especially in their current field of strength, the rising cleantech sector. This study enables Nordic countries and companies to take tangible steps towards more sustainable use of REMs and other critical metals.

Bente Naess
Norwegian Ministry of the Environment

Summary

Metals in various forms and uses are a central part of the global economy and have become increasingly important. Metals are also needed in the transition to a low-carbon and resource efficient economy.

Despite the fact that many metal extraction operations have become more sustainable over the past 20 years, especially in the developed countries, many environmental problems still exist. Mining sites are an environmental security concern both locally and regionally.

Manufacturers of end products are not necessarily aware of the potential adverse impacts created in the raw material extraction and processing phase. One of the major challenges for companies is tracing the origin of the metals used in their products. Metal supply chains are complex and involve various different actors such as miners, traders, refiners and manufacturers.

This study, commissioned by the Sustainable Consumption and Production Working Group of the Nordic Council of Ministers, was conducted to create a picture of the supply chain of selected Rare Earth Metals (REMs) and other critical metals used in the clean technology (cleantech) sectors of electric vehicles and solar panels (photovoltaics).

Objectives of the study were to:

- Examine the supply chain of rare earth and critical metals used in the cleantech sectors of electric vehicles and photovoltaics and the environmental problems related to them.
- Present on-going initiatives, policies and schemes addressing the environmental impacts of REMs and critical metals.
- Map the awareness of cleantech companies in Nordic countries of the problems related to rare earth and other critical metals in addition to their current actions and needs to further address these problems.
- Provide suggestions for tangible actions on improving problems related to metals and recycling and present a roadmap for sustainable Nordic metals use.
- Present a clear and concise set of conclusions and recommendations that can be used as a basis for communication and applied broadly in the cleantech as well as other sectors.

REMs are used in cleantech applications due to their unique chemical, magnetic and electrical characteristics. Despite their name, they are not actually considered rare but have significant environmental impacts in the raw material extraction and processing phase.

Cleantech comprises of new technologies and business models that offer benefits for customers while providing solutions to global environmental challenges. The negative impacts related to REM use need to be considered in comparison to the benefits of cleantech technologies. In electric vehicles, REMs are used in many applications, for example in the permanent magnets of electric motors. The use of REMs in photovoltaics is more limited, although electric system components may contain some REMs to a certain extent.

Traceability of REMs and critical metals, and accountability for social and environmental impacts in their extraction, is challenging. The metals are often procured through long supply chains and from regions with limited regulatory requirements for transparency. There is also insufficient information on how the impacts of metals extraction are specifically allocated to REMs and critical metals used from a life cycle assessment perspective. Although the supply chain is long, much can be done to make the supply chain more responsible and sustainable both in the raw material phase of the supply chain and in the end-of-life phase by improving the re-use and recycling rates of metals.

To mitigate the potential problems related to REMs and critical metals, companies will need to develop their knowhow and procurement processes. The resource requirements for adequate development can become prohibitive, especially for small and medium-sized companies.

Cleantech solutions are still under development, and they have been in use for only short periods of time and in limited quantities. As the use of cleantech technologies spreads, so does the importance of developing effective methods for re-using cleantech technologies and recycling materials. Currently, recycling of REMs and critical metals are often not profitable because the substances are found in small quantities and in complex systems. Increasing metal recycling rates is a key part of the path to sustainable metals use.

The recycling of PV modules and materials is already discussed, and recycling of PV modules is becoming mandatory through the European Union Waste Electrical and Electronic Equipment Directive (WEEE Directive). For REMs used in electric vehicles, the recycling requirements come through producers' responsibility that requires certain recyclability for the whole vehicle. However, as the amounts of REMs used are relatively small, they do not necessarily fall under the required recycling rates as they are formulated in current EU directives such as the WEEE-directive and ELV-directive.

On the basis of this study, the recommendations to develop sustainable metal use in the Nordic area can be summarised as three initiatives:

1. Awareness platform and roundtable initiative (short-term): Establish an information sharing and collaboration roundtable for interested parties. The Nordic Council of Ministries could support the roundtable directly by providing financial or organisational resources for such initiative, or by supporting the establishment of the roundtable. In addition the Nordic countries could use other communication measures to increase awareness on potential issues in the supply chain of REMs. In practice, sector wide guidelines or checklists could be developed.
2. Research and information gathering (mid-term): The use of cleantech will increase as companies strive to develop effective solutions to meet global environmental challenges. To better understand and to enable the mitigation of the negative environmental and social impacts of REMs, further research and information on the impacts of metals use in the whole value chain is needed. Sustainable REMs and other critical metals use could benefit from a Nordic research project or program.
3. Closed-loop solutions development (long-term): As an alternative, there is at least in theory a lot of potential in the re-use of components and recycling of materials. A long-term goal would be closed-loop processes, where re-use and recycling completely replace the need for mining and new material intake to the process. The concrete initiatives could include support for R&D&I activities in re-use and recycling of REMs and other critical metals in cleantech.

Glossary

ALD	Atomic layer deposition
a-Si	Amorphous Silicon
ASM	Artisanal & small-scale mining
CASM	Communities and Small-scale Mining
CdS	Cadmium sulphide
CdTe	Cadmium-Telluride
CERES	Centre Européen pour le Recyclage de l'Energie Solaire – the European recycling organization for end-of-life photovoltaic modules
CFS	Conflict-Free Smelter
CIGS	Copper-Indium-Gallium-Diselenide
CIS	Copper-Indium-Diselenide
CLM	Conventional Large Car, Medium-Specified
CMH	Conventional Midsize Car, High-Specified
CML	Conventional Midsize Car, Low-Specified
CPV	Concentrator PV technologies
c-Si	Crystalline silicon
EFTA	European Free Trade Association
EICC	Electronic Industry Citizenship Coalition
ELV	End of life vehicle
EOL	End-of-life
EPIA	European Photovoltaic Industry Association
EV	Electric Vehicle
GaAs	Gallium arsenide
GeSI	Global e-Sustainability Initiative
GRI	Global Reporting Initiative
HEV	Hybrid electric vehicles
HMM	Hybrid Midsize Car, Medium Specified
ICMM	International Council on Mining and Metals
ICMM	International Council on Mining and Metals
IEC	International Electrotechnical Commission
IMDS	International Material Data System
ITO	Indium-tin-oxide
ITS	Innotech Solar
LCA	Life Cycle Assessment
mc-Si	Multi-Crystalline
MMSD	Mining, Minerals and Sustainable Development
MMSS	Mining and Metals Sector Supplement

MWp	Megawatt-peak
OECD	Organisation for Economic Co-operation and Development
PHEV	Plug-in hybrid electric vehicles
PV	Photovoltaic
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
REM	Rare Earth Metal
sc-Si	Single Crystalline
SEC	U.S. Securities and Exchange Commission
SGU	Geological Survey of Sweden
Sm-Co	Samarium-cobalt
STC	Standard Test Conditions
TCO	Transparent Conductive Oxide
UL	Underwriter Laboratory
WEEE	Waste Electrical and Electronic Equipment Directive
μc-Si	Micromorph Silicon

1. Introduction

1.1 Background

Metals form a centre-piece of global economy and have become increasingly important. Metals are also needed in the transition to a low-carbon and resource efficient economy.

Over the past 20 years, several improvements have occurred in mining operations and the environmental consequences of metal extraction. Some examples of projects, initiatives and active organisations addressing sustainability issues of mining include the Mining, Minerals and Sustainable Development (MMSD) project, which led to the establishment of the International Council on Mining and Metals (ICMM), the Framework for Sustainable Mining, and the Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development. However, many mining sites (prospective, operational and closed) still cause tensions with and within communities. In addition, mining sites are a potential environmental security concern locally and regionally, and social and environmental problems are still occurring.[1]

Environmental concerns related to metal extraction and processing include:[2]

- Impacts to physical landscapes as a result of mining, waste rock and facility development.
- Increase in acidity of soils and water contaminating vegetation and release of metals to the environment.
- Risk of radioactive pollution at the extraction sites.
- Degradation of surface and groundwater quality.
- Increase in air-borne dust and other emissions such as sulphur dioxide and nitrogen oxides from smelters contaminating the atmosphere and surrounding areas. Therefore, mining causes carbon emissions and contributes to climate change.

Metal extraction has also been linked, for example, in Congo to fuelling the armed conflict. In addition, poor practice has created environmental

[1] Material produced within Gaia's project: "Environmental security, mining and good governance" for the Ministry for Foreign Affairs of Finland, 2011.
[2] Hudson et al (1999).

and health problems.[3] In Zambia, the Zambia environmental management agency ordered to shut down a copper treatment plant belonging to Glencore International's Mopani Copper Mines in 2012 due to pollution violations.[4] Several metals used in green technology, defence systems and consumer electronics come solely from China adding a geopolitical aspect to the social and environmental problems.

For end product manufacturers, poor social and environmental practices in the raw material extraction and processing phase can cause severe harm to their reputation. Concerns raised by non-governmental organisations and other organisations have initiated changes in how companies view their metals use. For example, the issue of conflict minerals from Congo has received much media attention and has led many electronic companies to examine their supply chain more closely. Several companies such as Nokia, HP, Cisco, Intel, Samsung and many others have conflict mineral policies.[5] In addition, industry coalitions such as the Electronic Industry Citizenship Coalition (EICC) and Global e-Sustainability Initiative (GeSI) have taken actions to address responsible material sourcing such as by developing a Conflict-Free Smelter (CFS) program.[6]

One of the major challenges for companies is tracing the origin of the metals used in their products. Metal supply chains are complex and involve various different actors such as miners, traders, refiners and manufacturers. Although the supply chain is long, much can be done to make the supply chain more responsible and sustainable. One major aspect, in addition to the raw material phase of the supply chain, is to focus on the end-of-life phase of products and the potentials to improve the re-use and recycling rates of metals. Recycling rates of metals are in many cases far lower than their potential for re-use.[7] Therefore, raising metal recycling rates is a key part of the path to green economy.

1.2 Objectives and scope of the study

The aim of this study funded by the Nordic Council of Ministers is to create a picture of the supply chain of selected Rare Earth Metals (REMs) and other critical metals used in clean technology (cleantech) products and solutions. Cleantech has been chosen due to the fact that it is a rapidly growing sector and will face similar problems related to metal use as, for example, electronics companies have for a longer period of time. As clean-

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[3] See e.g. UNEP (2011b).
[4] Reuters (2012).
[5] Google search result of "conflict mineral policy."
[6] EICC (2012).
[7] UNEP (2011a).

tech represents cleaner and greener solutions for energy production, transport, waste management and other areas, the sustainability of these solutions, including the environmental impacts of the metals used in the products, form an interesting and important aspect to examine.

The focus of the study is in particular on the cleantech sectors of electric vehicles and solar panels (photovoltaics). These cleantech sectors were selected as electric vehicles rely heavily on REMs, which have significant environmental impacts in the raw material extraction and processing phase. Photovoltaics on the other hand, represent a growing technology area with possible large resource consumption and currently, there is more information needed on the possible waste and recycling problem, and problems along the product chain.

The study examines how cleantech companies, especially in the context of Nordic countries, are aware and acting on the problems related to the lifecycle of metals and what are the potentials to minimise environmental impacts. The study results with recommendations and conclusions for Nordic cleantech companies on why they should and how they can pay more attention to their supply chain and improve sustainability.

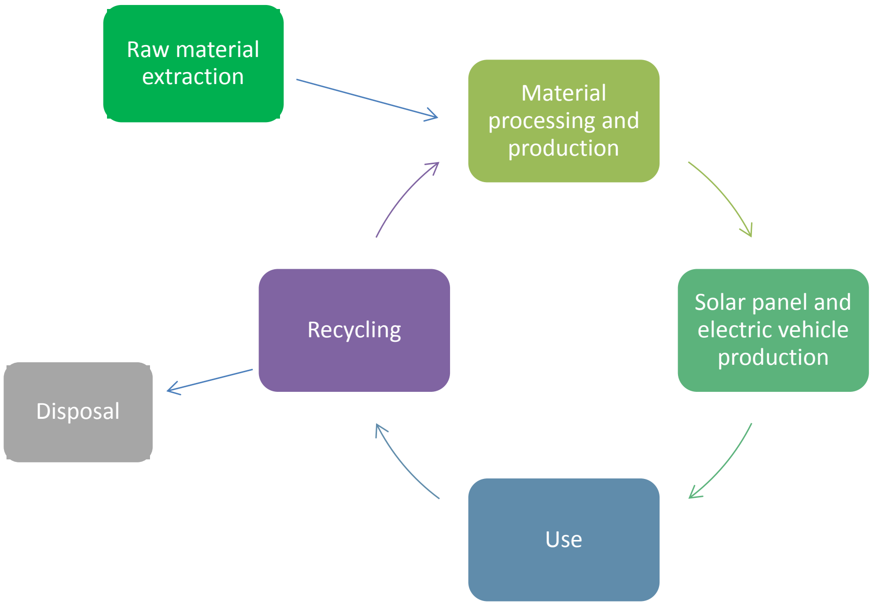
In summary, the objectives of the study are to:

- Examine the supply chain of rare earth and critical metals used in the cleantech sectors of electric vehicles and photovoltaics and the environmental problems related to them.
- Present on-going initiatives, policies and schemes addressing the environmental impacts of REMs and critical metals.
- Map the awareness of cleantech companies in Nordic countries of the problems related to rare earth and other critical metals in addition to their current actions and needs to further address these problems.
- Provide suggestions for tangible actions on improving problems related to metals and recycling and present a roadmap for sustainable Nordic metals use.
- Present a clear and concise set of conclusions and recommendations that can be used as a basis for communication and applied broadly in the cleantech as well as other sectors.

1.3 Limitations of the study and structure of the report

This study focuses on those metals used in electric vehicles and photovoltaics, which belong to the Rare Earth Metals group or to a group of other critical metals. Critical metals are defined in this report as metals with relevant environmental impacts in the supply chain and/or create challenges to the sustainability of the product's life cycle. The study covers the whole life cycle from raw material extraction to the user phase and recycling (Figure 1.1.). However, specific phases that have most significant environmental impacts are prioritised.

Figure 1.1 Life-cycle of metals used in cleantech products



Main methods used in the study were literature review, web survey to Nordic cleantech companies, case studies including in-depth interviews with selected actors, as well as and analysis.

The work was carried out by a consortium that was led by Gaia,[8] U&We AB from Sweden and Ethical Trading Initiative Norway. Steering group members of the Nordic Council of Ministers included Eva Ahlner (Naturvårdsverket, Sweden), Gert Hansen (Danish EPA), Jón Geir Pétursson (Ministry for the Environment, Iceland) and Camilla Sederholm (Finnish Environment Institute).

The structure of the report is as follows. Chapter 2 describes main Rare Earth Metals and other critical metals used in electric vehicles and photovoltaics and the environmental impacts related to them. Chapter 3 presents initiatives, policies and schemes, which address the sustainability issues of metal use in the extraction and recycling and re-use phase. Chapter 4 presents results of a web survey carried out to Nordic cleantech companies as well as case studies of companies working in the field of electric vehicles and photovoltaics. Chapter 5 includes analysis of the study and finally, chapter 6 presents the conclusions and recommendations.

[8] Gaia Global SA in Switzerland and Gaia Consulting Oy in Finland.

2. Rare Earth Metals and other critical metals used in electric vehicles and solar panels

2.1 Definition and background of Rare Earths Metals

Rare Earth Metals (REMs) are used extensively in cleantech applications such as wind turbines, electric vehicles (EVs), hybrid electric vehicles (HEVs) and plug-in hybrid electric vehicles (PHEVs) due to their unique chemical, magnetic and electrical characteristics. REMs are however also used widely in other areas like electronics giving great sound to small loudspeakers. Despite their name, REMs are not actually considered rare but are hard and expensive to extract. The process for extracting these metals and isolating the ores in which they are found can be difficult and environmentally hazardous, which is why they form a significant segment in examining environmental impacts along the supply chain of electric vehicles.[9]

Rare Earth Metals (REMs) are classified as those chemical elements with atomic numbers between 57 and 71. These include 15 metals from the chemical group called the lanthanides: lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, and lutetium. In addition scandium (Sc, 21) and yttrium (Y, 39) are grouped within the lanthanide family because of their similar properties, resulting in a total number of 17 rare earth metals (Figure 2.1).[10]

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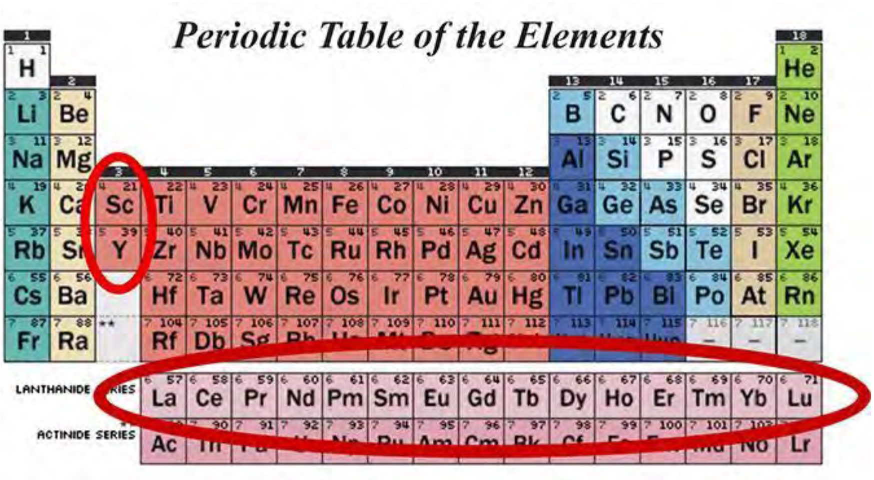
[9] Sadden (2011).
[10] Sadden (2011).

Figure 2.1 Rare Earth Metals (REMs) situated in the Periodic Table[11]



REMs can be found in around 200 minerals. China is in a monopoly situation with a 95% share of the market.[12] China dominates REM exports and for example in 2010, the United States was 100% import dependent of rare earth oxides. The United States was previously one of the prominent rare earth producers but closed its mine due to environmental concerns and the difficulty of competing with China's rare earth prices. China has decreased its rare earth exports since 2005.[13] Due to these geopolitical issues and increased prices, the United States, among others, is looking into increasing domestic mining of REMs and finding substitutions. Other countries with major REM findings are Australia and South Africa.[14] The main focus seems to be to find new sites for extraction as the demand of REMs is expected to increase due to the increased demand of, among others, green technology. Starting up new production facilities, however, takes around ten years and involves high investment costs.[15]

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[11] http://www.cliffkule.com/2010/10/china-halts-rem-exports-to-u.html

[12] Paul & Campbell (2011).

[13] Meyer & Bras (2011).

[14] Paul & Campbell (2011).

[15] Eriksson and Olsson (2011).

[15] Weiss et al (2000).

2.2 Metal use in electric vehicles

2.2.1 The Electric Vehicles market

Electric vehicles are one of several emerging solutions for more sustainable transportation. The market share, however, was only 1% in 2009 of the total passenger car market. The challenges involve finding suitable business models, developing frameworks that support the business models, and to developing cost efficient technologies for batteries and engines. The high cost of electric vehicles is one obstacle on the demand-side.[16] The target group, initially, are not private consumers but larger actors such as private companies and municipalities. By 2020 to 2025 the market share for electric vehicles in Europe is estimated to be 3–10%, and 450,000 – 1,500,000 units are expected on the road.[17]

Electric vehicles have some generic characteristics that distinguish them from conventional vehicles. The most important differences from a sustainability perspective are the following:[18]

- Driveline.
    a) Batteries are the main component.
    b) Power electronics are used more extensively.
    c) Motor control is required to a higher degree.
    d) The use of electric motors instead of combustion engines.
- High demands on low weight.
    a) A lighter car panel, i.e., carbon fibre composite.
    b) A lighter automobile platform.
- High demands on aero dynamics.
- Special demands on heating.
    a) A separate heating system.

The use of REMs in batteries and electric motors form a central point of view for this study and these aspects are discussed more in detail below.

2.2.2 Metals used in EVs

Steel and aluminium are the main metals used in automobile production and will probably continue to be in the foreseeable future.[19] REMs are used extensively in electric vehicles as well as other green technology such as wind power turbines as they increase efficiency and decrease

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[16] Narich et al. (2011).
[17] European Parliament (2010).
[18] Johansson and Wrenfelt (2011).
[19] Weiss et al (2000).

weight in products.[20] Examples of REMs used in different parts of electric vehicles are presented in Figure 2.2. REMs are used in several components of the electric vehicle. However, the volumes of REMs in these components are marginal relative to the volumes used in permanent magnets of the electric motors and in batteries.

Figure 2.2 Examples of Rare Earth Metals used in an electric vehicle[21]

REMs are used both in permanent magnets of electric motors (Praseodymium, Neodymium, Samarium and Dysprosium) and batteries (Lanthanum, Cerium, Praseodymium, Neodymium, Cobalt and Lithium).[22] Most commonly there are two types of permanent magnets. One of them is the Nd-Fe-B magnet, often referred to as neodymium magnet. The second type is the samarium-cobalt (Sm-Co) type magnet. The Sm-Co magnets were introduced in the 1970's and this lead to an expansion in the usage of permanent magnets. The characteristics of these two types are somewhat similar but the neodymium magnets have a higher magnetic energy density, which makes it a better choice for wind turbines and electric vehicles. Due to the high energy density in permanent magnets, they often replace electromagnets in many types of applications. This is due to the fact that no external energy source is needed to provide the magnetism.[23]

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[20] U.S. Department of Energy (2010a).
[21] Molycorp (2012).
[22] U.S. Department of Energy (2010a).
[23] Eriksson and Olsson (2011).

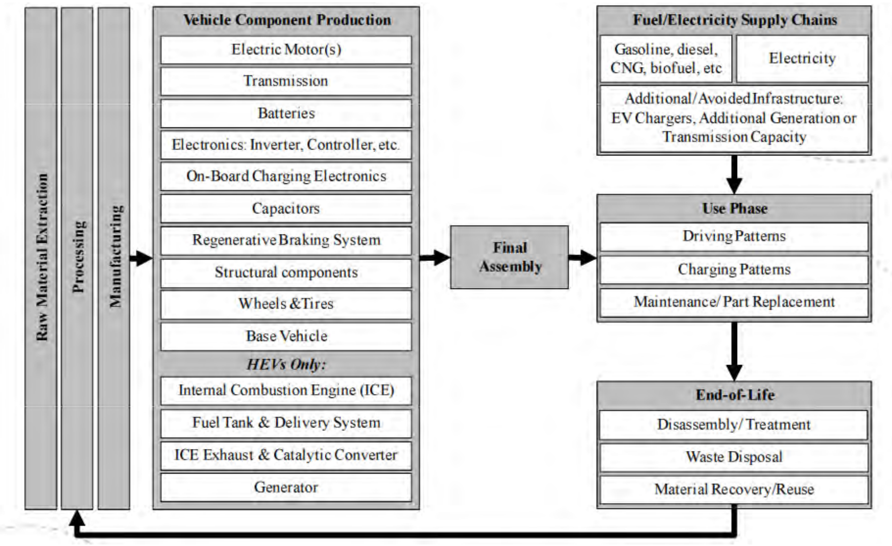
Lithium and cobalt are used widely in batteries of electric vehicles. A positive aspect of lithium in batteries is that it can be reused, and depleted batteries can be recycled.[24]

2.2.3 *Life Cycle Assessment of EVs*

From a life cycle perspective, the largest environmental impact from an electric vehicle occurs, as opposed to a conventional vehicle, in the production phase and not in the use phase.[25]

A schematic view of the life cycle of a battery equipped electric vehicle is shown in Figure 2.3. The environmental and social problems mainly occur in the processes of raw material extraction and processing, as well as in the end-of-life phase depending on the techniques used and collection potentials.[26]

Figure 2.3 Life Cycle Assessment of NiMH and Li Ion Cycle Assessment of NiMH and Li- Battery Electric Vehicles[27]



2.2.4 *Raw material extraction and processing phase*

Rare Earth Metals

The major negative environmental impacts from the production of REMs stem from the mining and chemical processing of the metals.[28] Rare

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[24] Canis (2011).
[25] Weiss et al (2000)
[26] Johansson & Wrenfelt (2011).
[27] Majeou-Bettez et al (2011).
[28] Majeou-Bettez et al (2011).

earth mining is both financially and environmentally demanding. The concentrations of rare earth metals in ores are typically low. Ores must go through a concentration and separation process which can involve several different techniques such as crushing, multiple separation processes and refining.[29]

Environmental problems associated with the mining of rare metals are similar to that of other types of mining. Mining processes are water demanding and can lead to land destruction, waste production and radioactive waste. The mining processes are also energy intensive and there are risks of leakage of other metals and substances, such as fluorine, aluminium, arsenic, beryllium, cadmium, copper and lead. Water related risks include pollution of drinking water, contamination of groundwater, surface water run-off and acidification. Problems are also associated with closing down the mining sites, as is also the case in conventional mining. The negative environmental impacts will most likely increase as the demand for the metals increases.[30]

Different REMs have different characteristics and hence need to be handled differently, both during the extraction and at the stage of chemical processing.[31] The chemical processes can affect air quality, as dust and fumes are emitted. This stage does not only involve the use of chemicals, but as REMs might need to be processed several times at different geographical locations, the negative environmental impacts from transportation also need to be taken into consideration. During the whole production chain of REMs, careful and costly handling is needed to avoid leakage to the natural environment.[32]

As mentioned in chapter 2.1, China is currently the largest exporter of REMs in the world and is facing large challenges regarding environmental issues and workers' health. The social, environmental and economic issues of REMs extraction in China are summarized in Table 2.1.

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[29] Meyer and Bras (2011).
[30] Paul and Campbell (2011).
[31] Canis (2011).
[32] Majeou-Bettez et al (2011).

Table 2.1 Summary of social, environmental and economic risks related to Rare Earth Metals in China [33]

Environmental Issues	Low risk	Medium risk	High risk
Water Pollution			■
Air Pollution		■	
Land Destruction		■	
Radioactive Waste			■
Social Issues	**Low risk**	**Medium risk**	**High risk**
Freedom of Association and Protection of the Right to Organise			■
Child Labour		■	
Discrimination (Employment and Occupation)		■	
Forced Labour		■	
Health Risk in Production			■
Economic Issues	**Low risk**	**Medium risk**	**High risk**
Corruption and Bribes			■
Black Market			■
Risk of Conflict		■	
Exploitation of local society			■

Currently, the main focus in China is to create stricter environmental laws and work against illegal mining. In cases of illegal mining the compliance with environmental and safety laws are even more flawed.[34] Another strategy is to create larger production facilities, to increase the control and facilitate the supervision and monitoring.[35] Another approach to minimize the negative environmental impacts from the production of REMs is to increase the efficiency of production.[36]

Lithium and cobalt

Lithium is mainly mined in the form of salt brine. Bolivia has currently the largest deposits of lithium followed by Chile and China. The mining process has environmental impacts, but in comparison with other mining processes to a limited degree.[37] The main threat is to water organisms, and therefore special attention should be paid to water use and to contamination of water.[38]

Cobalt is linked to severe problems in the extraction and processing phase. Over half of worldwide cobalt production[39] is mined in Zambia and the Democratic Republic of Congo in the so-called Copperbelt region[40], where several environmental problems from cobalt mining have been revealed. Some examples are:[41]

[33] Johansson and Wrenfelt (2011).
[34] Hurst (2010).
[35] National Institute of Advanced Industrial Science and Technology (2008).
[36] Paul and Campbell (2011).
[37] Johansson and Wrenfelt (2011).
[38] Canis (2011).
[39] Finland is also a producer of cobalt, but production volumes are globally small (see e.g. http://www.indexmundi.com/minerals/?product=cobalt&graph=production).
[40] Rajala (2008).
[41] Nordbrand and Bolme (2007).

- Severe pollution of rivers and air.
- Extensive land destruction.
- Risk for radioactive uranium in the slag dumps.

A summary of social, environmental and economic issues related to the extraction and processing of cobalt are shown in Table 2.2.

Table 2.2 Summary of risks related to Cobalt analysed by the situation in Congo[42]

Environmental Issues	Low risk	Medium risk	High risk
Water Pollution			
Air Pollution			
Land Destruction			
Radioactive Waste			
Social Issues	**Low risk**	**Medium risk**	**High risk**
Freedom of Association and Protection of the Right to Organise			
Child Labour			
Discrimination (Employment and Occupation)			
Forced Labour			
Health Risk in Production			
Economic Issues	**Low risk**	**Medium risk**	**High risk**
Corruption and Bribes			
Black Market			
Risk of Conflict			
Exploitation of local society			

2.2.5 Manufacturing phase

The main environmental impacts of electric vehicles in the manufacturing and vehicle production phase relate to the use of energy and CO_2 emissions emitted during the manufacturing of electric cars. The environmental impacts linked specifically to Rare Earth Metals cannot be separated from the overall impacts in the production phase.

In 2011, Volvo conducted a study on potentially critical metals in collaboration with Chalmer University of Technology. The aim of the study was to map the use and the quantities of potentially critical metals in Volvo's products, to be able to manage the use in the best way. The study examined 31 materials, including REMs, Platinum Group Metals and other potentially critical metals. The analysis showed that potentially critical metals were found in 555 unique parts out of 1 821 parts in total in the Hybrid Midsize Car, Medium Specified (HMM).[43]

The conclusion was that the HMM contained more potentially critical materials than the conventional car models. The study also showed that

[42] Johansson and Wrenfelt (2011).
[43] Cullbrand and Magnusson (2011).

electronics play an important role in the use of potentially critical metals, independent on whether it is a conventional diesel or hybrid vehicle.[44]

The materials with increased presence in the HMM were: neodymium, dysprosium, copper, samarium, silver, terbium, manganese, lithium, palladium and platinum. The largest amounts of metals found were copper, manganese, magnesium and lithium (Figure 2.4) followed by Molybdenum, Neodymium, Niobium, Cobalt, Dysprosium and Silver (Figure 2.5).[45]

Figure 2.4 Total mass per car and materials with more than 1 kg identified in at least one of the cars, HMM being the hybrid car and the three others being different conventional cars[46]

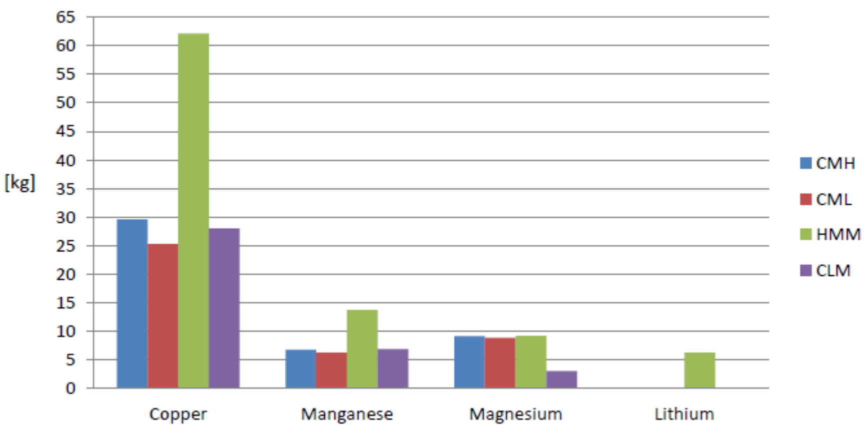
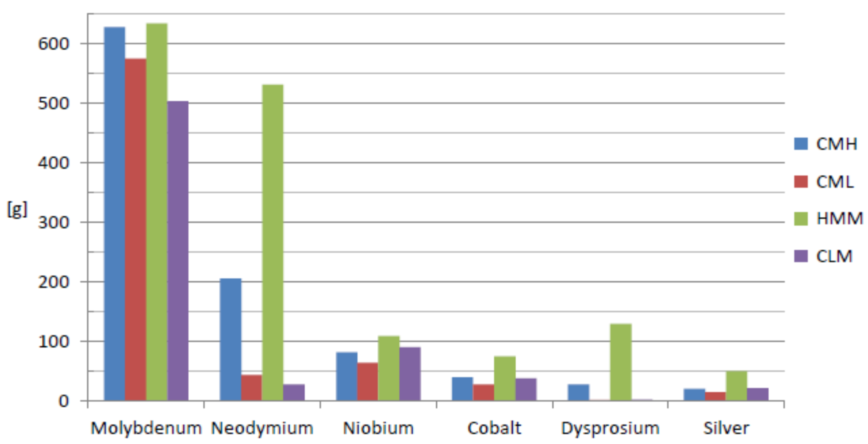


Figure 2.5 Total mass greater than 45g but less than 1kg in at least one of the cars[47]



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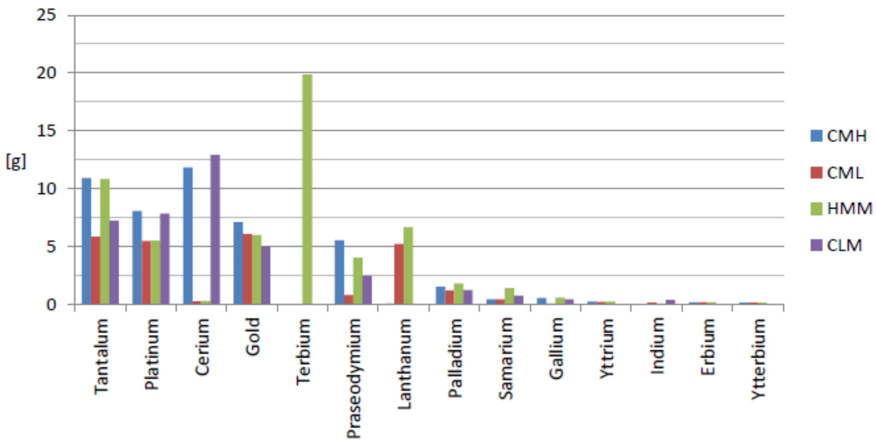
[44] Cullbrand and Magnusson (2011).
[45] Cullbrand and Magnusson (2011).
[46] Cullbrand and Magnusson (2011).
[47] Cullbrand and Magnusson (2011).

Additional potentially critical metals found, but in quantities lower than 45g are illustrated in Figure 2.6.

***Figure 2.6 Total mass greater than 0.5g but less than 45g in at least one of the cars*[48]**



2.2.6 Recycling and end of life phase

Currently, approximately 25% of iron metals in automobiles are recycled globally.[49] According to the European Union ELV directive (see chapter 3.2.1), 80% of a vehicle must be retrieved for recycling while another 5% must be collected and used in energy-recovery processes. By 2015, these targets rise to 85% for recycling plus an additional 10% for energy recovery.[50] Especially in developing countries, there are health issues related to the recycling of metals as much work is done manually.[51] Regarding other main materials, such as plastics, small amounts of materials are recycled and the challenges of doing so are still large.[52]

There are currently no solutions for recycling of batteries in electric vehicles. Research is on-going on how to recycle NiMH and Li-ion batteries in an environmental and economically sustainable way. The research takes place both at universities and by corporate actors around the world. However, due to economic aspects information is held confidential by corporate actors.[53, 54]

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48 Cullbrand and Magnusson (2011).
49 Sullivan and Gaines (2010).
50 Waste Management World (2012).
51 Sullivan and Gaines (2010).
52 Weiss et al (2000).
53 Ekberg et al.
54 Personal communication, Christian Ekberg, Chalmer University of Technology.

Currently, the recycling rates of REMs are less than 1%.[55] For example in the US, there are currently no efficient recycling methods in place for the recycling of REMs from electronics, electric motors and other scrap materials. The main issue with recycling of REMs is that the technology is not well developed and is very cost intensive. According to an examination based on rare earth prices from March 2011, hybrid car's NiMH batteries contain between USD 165 and USD 250 of rare earth per battery (such as lanthanum, cerium, praseodymium and neodymium).[56]

Researchers have found methods to extract rare earths from metal alloys,[57] like those in NiMH batteries, with over 97% laboratory recovery rates.[58] However, most of these methods used in lab settings have not been transferred over to the industrial sector.[59]

One problem in the area of recycling is the lack of coordination between car manufacturers, battery manufacturers and recycling companies. The cost of recycling is high and the value of the materials does not exceed the recycling costs. Business models need to be developed that encourage the recycling of batteries. Alternatives could be governmental initiatives to develop recycling facilities or deposit systems.[60]

Most EV/hybrid manufacturers are moving from NiMH batteries towards lithium-based batteries as this technology is not reliant on REMs.[61] However, the recycling rates of lithium are also low, but as mentioned above, lithium has less environmental impacts in the raw material phase than REMs.

Regarding electric vehicle motors and magnets, there are currently research programmes on-going to improve recyclability and reduce the use of rare metals such as the MORE (MOtor REcycling) project (see below).

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[55] Moss et al (2011).
[56] Schüler et al (2011).
[57] a mixture or *metallic* solid solution composed of two or more elements.
[58] Schüler et al (2011).
[59] Schüler et al (2011).
[60] Personal communication, Christian Ekberg, Chalmer University of Technology.
[61] Kara et al (2010).

MORE (MOtor REcycling) project

A consortium of actors in Germany have joint a consortium in a research project More (MOtor Recycling, 2011-2014) to develop recycling solutions for electric vehicle motors. The partners in the project will consider the entire value chain from design and manufacturing of engines to reverse logistics and reuse in vehicles.

In MORE the researchers are following different approaches for recycling electric motors: removing the heavy magnets weighing about one kilogram from end-of-life motors, repairing and subsequently reusing the electric motor or its components, as well as reusing the magnetic materials, raw materials and rare earth metals after they have been recovered from pre-sorted and shredded materials. Furthermore, concepts will be developed for a motor designed to be easier to recycle as well as for ecological efficiency analyses and models of material closed loops.

The project is funded by the German Ministry of Education and Research (BMBF) and the consortium is led by industrial conglomerate Siemens. Other partners are Daimler, Umicore, Vacuumschmelze, Friedrich-Alexander-Universität Erlangen-Nürnberg, Technische Universität Clausthal and Öko-Institut.

Results of the projects are scheduled to be presented in 2014.

2.2.7 Substitutes of metals used in EVs

One area for the substitutes of REMs in EVs is nanomaterials, where intense research is on-going to find new battery material as well as new lightweight materials for the car body. However, the control and follow up from authorities as well as the knowledge of the environmental and health risks associated with nanomaterials are limited. The European Community Regulation on chemicals and their safe use, REACH, includes the field of nanomaterials. However due to the specific properties of nanomaterials the REACH regulations may not be efficient. This is due to the fact that REACH goes by weight and chemical description and nanomaterials are used in small volumes and may be seen as harmless if looking at only the chemical description.[62]

Nanoparticles may enter into and spread in the human body in ways normal particles are not capable of. This means that materials that have been considered harmless change properties, which can affect the human body in negative ways. The risks regarding nanomaterials are summarized as:[63]

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[62] http://miljoforskning.formas.se/sv/Nummer/Augusti-2009/Innehall/Temaartiklar/REACH-missar-nano/

[63] Johansson and Wrenfelt (2011).

- Exposure.
  a) Loose nanoparticles and nanotubes could have high movement.
- Toxicity.
  a) Traditional properties may change completely in nanoscale.
  b) Increased reactivity may be toxic by itself.
- Secondary effects.
  a) Nanoparticles may act as a carrier to toxic particles.

2.3 Metal use in solar panels

2.3.1 PV market and technologies

Solar photovoltaic (PV) power is a commercially available and reliable technology with a significant potential for long-term growth in nearly all world regions.[64] Compared to other forms of renewable energy, the rate of growth in the sector over the last years has been significant.[65] The outlook for the installed capacity of PV between now and 2050 expects a yearly growth of 19% between 2012 and 2020, 14% till 2030, 6% till 2040 and 4% till 2050.[66]

The European Photovoltaic Industry Association (EPIA) expects that by 2020 silicon wafer-based technologies will account for about 61% of sales, while thin films will account for around 33%. Concentrator PV (CPV) and emerging technologies such as organics will account for the remaining 6%.[67]

PV systems (see Figure 2.7)[68] directly convert solar energy into electricity. The basic building block of a PV system is the PV cell, which is a semiconductor device that converts solar energy into direct-current electricity. PV cells are interconnected to form a PV module, typically up to 20–200 Watts. The PV modules combined with a set of additional application-dependent system components (e.g. inverters, batteries, electrical components and mounting systems), form a PV system. PV systems are highly modular, i.e. modules can be linked together to provide power ranging from a few watts to tens of megawatts.[69]

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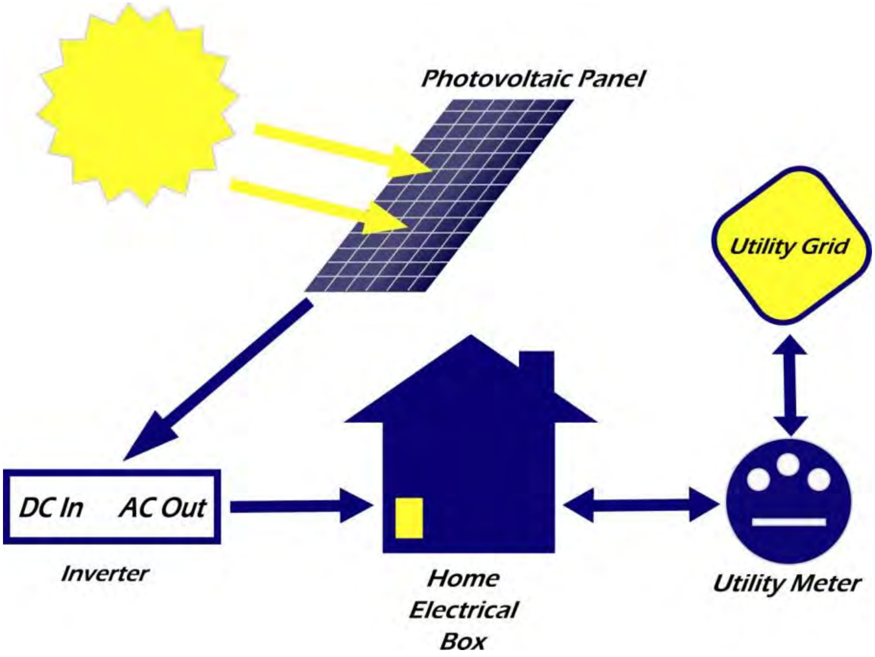
[64] IEA (2010).
[65] Bleiwas (2010).
[66] Angerer et al (2009).
[67] Greenpeace and EPIA (2011).
[68] Simplex Solar (2012).
[69] IEA (2010).

Figure 2.7 Grid-tied PV system[70]



Commercial PV modules can be divided into two broad categories: wafer based crystalline silicon (c-Si) modules and thin films. There are a range of emerging technologies, including concentrating photovoltaics and organic solar cells, as well as novel concepts with significant potential for performance increase and cost reduction.[71]

Crystalline silicon PV modules are based on wafer-based c-Si. Crystalline silicon PV modules represent 85–90% of the global annual market today. C-Si modules are subdivided in two main categories: single crystalline (sc-Si) and multi-crystalline (mc-Si).[72]

Thin films are made by depositing extremely thin layers of photosensitive materials in the micrometer range on a low-cost backing such as glass, stainless steel or plastic. The main advantages of thin films are among others their relatively low consumption of raw materials. Currently thin films account for 10–15% of global PV module sales. They are subdivided into three main families:

1. Amorphous (a-Si) and micromorph silicon (a-Si/μc-Si),
2. Cadmium-Telluride (CdTe),

[70] Simplex Solar (2012).
[71] IEA (2010).
[72] IEA (2010).

3. Copper-Indium-Diselenide (CIS) and Copper-Indium-Gallium-Diselenide (CIGS).[73]

The most widely used thin film technology due to the best efficiency-cost ratio is the CdTe technology. In 2011, it cost about 30% less than CIGS technology and 40% less than a-Si technology.[74]

Emerging technologies encompass advanced thin films and organic cells. The latter are about to enter the market via niche applications. Concentrator PV technologies (CPV) use an optical concentrator system which focuses solar radiation onto a small high-efficiency cell. CPV technology is currently being tested in pilot applications. Novel PV concepts aim at achieving ultra-high efficiency solar cells via advanced materials and new conversion concepts and processes. They are currently the subject of basic research.[75]

2.3.2 Metals used in PV technologies

The diversity of photovoltaic cell technologies has resulted in an even higher diversity of materials used in their manufacturing.

Raw materials used for PV cells are mainly mono-crystalline silicon, poly-crystalline silicon, amorphous silicon, cadmium, tellurium, gallium, germanium, indium, silver and selenium. Copper, zinc and aluminum are further materials used in the production of PV panels.[76]

Currently, PV producers are competing with other more price sensitive industries/technologies (e.g. microelectronics) for raw materials. Demand growth for gallium is forecast to be around 10% per annum, which is mainly driven by fast growth in PV applications.[77] In addition, demand in indium and tellurium is expected to increase rapidly over the coming decade due to PV applications. Indium- and gallium-containing raw materials exist abundantly worldwide. The metals industry has been investing in process improvements and capacity over the last few years to bring more indium and gallium to the market.[78] Only a small fraction of this supply of gallium is economically recoverable. If gallium cannot be substituted in the near future and gallium supplies do not expand significantly within the two coming decades, CIS/CIGS photovoltaic cell manufacturing may suffer. [79]

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[73] IEA (2010).
[74] PVinsights.com (2011).
[75] IEA (2010).
[76] see European Parliament (2012) & Bleiwas (2010).
[77] Moss et al (2011).
[78] Phipps (2008).
[79] European Parliament (2012).

Rare earth metals (REMs) as defined in chapter 2.1 are currently not used in PV production. For organic PV ruthenium is used for its stability. Alternatives are based on zinc or metal free organic compounds.[80] Therefore the PV industry, even when looking at the PV system as a whole does not rely on REMs although system components such as inverters, batteries, and mounting systems might contain to a certain extent some REMs.

From the environmental perspective, raw materials used in PVs come with the environmental burden of the mining and production of primary metals (zinc, copper, lead etc.). Current discussions on environmental issues in the PV industry are primarily focused on energy payback times and recycling of PV modules and materials.

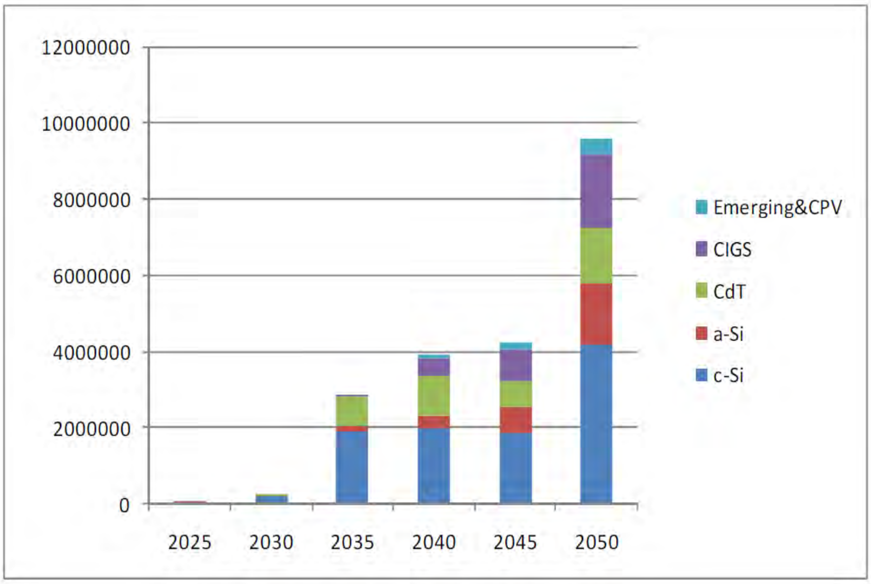
2.3.3 Recycling of PV modules

The more PV modules are installed, the more the market will encounter a challenge of proper recycling of end-of-life modules and reuse of recovered material.

Currently, most of the installed PV modules are still in use. Therefore, there are not many recycling facilities operating. Recyclers have not been interested in processing PV modules due to the limited volumes available. However, the reuse of materials such as silicon is already technically possible. Thus, the market still needs to be further developed (e.g. investments in recycling facilities) to become commercially interesting. Adequate recycling processes and systems need to be established as recycling is not possible if the modules are mixed with other waste.

[80] Angerer et al (2009).

Figure 2.8 Photovoltaic waste generated by technology annually in the EU-27 (in tonnes)[81]



As in Europe, Germany, Spain and Italy have the largest installed PV capacity and these countries will be the ones generating larger quantities of end-of-life modules in the coming decades. With a technical lifetime of 30 years, estimated volumes of photovoltaic waste in Europe are expected to more than triple by 2020 from 2010 figures. However, these figures have varied substantially in different studies even for estimates for a following 2–3 year time period. This is an indication of the immaturity of the market and the difficulty to predict its commercial and also technical developments.[82]

A challenge in recycling of photovoltaic panels is their long life time which is estimated 25 years. However, technical lifetime could be as long as 30 to 40 years. Not enough time has elapsed to be able to differentiate technical lifetimes between photovoltaic technologies.[83]

The amount of secondary raw materials from photovoltaic cells as well as from other technologies that use the same materials will be significant in the future, and the development of recycling schemes and technologies will be important. However, most of these materials will only be available in a few decades ahead when products have reached their end-of-life.[84]

Even though recycling will not be able to compensate for any significant part of the raw material supply needed for the successful deploy-

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[81] European Commission DG ENV (2011).
[82] PV CYCLE (2011).
[83] European Commission DG ENV (2011).
[84] European Parliament (2012).

ment of photovoltaic cells up to 2030 - tapping the full potential of urban mining and closing material cycles with appropriate global infrastructures is essential to establishing a green economy and to secure sustainable development.[85]

PV Cycle, a not-for-profit organization founded by PV manufacturers, proposed a voluntary recycling scheme for the photovoltaic industry to the European Commission in December 2010, but the proposal was rejected due to a number of concerns, including financing and target setting. After that, the European Commission decided to analyze the option of including photovoltaic panels in the scope of the WEEE-Directive to provide a solid ground for the ongoing discussions.[86]

Even though there is currently no legislation that regulates the collection and recycling of photovoltaic cells, and even though end-of-life photovoltaic cells are not expected to hit the market in any significant amount before 2025-2030 (see Figure 2.8), collection and recycling schemes are already being developed. PV CYCLE (see also Chapter 3.2.3) started its own voluntary recycling scheme which turned out to be successful, and they have recently announced the collection of 1020 tonnes of end-of-life photovoltaic modules.[87] PV CYCLE is cooperating with several recycling industries and is currently able to recover glass, cadmium, selenium, tellurium and indium.[88]

PV CYCLE is however not the only one setting up recycling schemes. Deutsche Solar has its own recycling scheme for crystalline silicon panels and can recover glass, silicon, aluminium, steel, silver, copper, lead and cadmium. First Solar has a recycling scheme for CdTe panels and is testing its methods on CIS/CIGS. Umicore, a metals refining and recycling company, has also developed recycling schemes for photovoltaics and is able to recycle CdTe, CIS/CIGS and indium-tin-oxide glass to recover metals like copper, indium, gallium, selenium and tellurium. Some of the mentioned recycling schemes can recover up to 90-95% of the input material - showing that photovoltaic recycling is feasible and will be possible to run on commercial scales in the near future.[89]

2.3.4 Recycling of recovered material

For indium, recycling of post industrial waste is common practice and already represents a major source of indium supply with production

[85] UNEP (2011a).
[86] European Parliament (2012).
[87] PV CYCLE (2011).
[88] European Parliament (2012).
[89] European Parliament (2012).

levels of secondary indium being at least as large as those for primary indium.[90]

The major usage of gallium is within semiconductors, which require that the refined material must have a very low concentration of impurities. Therefore sophisticated processing routes are required to ensure that this purity is produced. Only 15% of a gallium arsenide (GaAs) ingot is actually used during electronics manufacture, and the remaining 85% can be recycled. For 2010, world gallium recycling capacity was estimated at 141 tonnes versus 184 tonnes for primary production capacity.[91]

Figures for tellurium secondary production are unknown, although small quantities of new scrap from CdTe production are known to be recycled from PV solar cells. First Solar, a producer of CdTe solar PV, has implemented its own recycling scheme for pre-consumer scrap but also complete solar cells (see below).

First Solar's recycling scheme for pre-consumer scrap and complete solar cells

The world's largest producer of CdTe solar PV, First Solar, has implemented its own recycling scheme for both pre-consumer scrap and of complete solar cells collected free-of-charge from consumers. The process is operated in the US and Germany and involves shredding, removing the films using acid and hydrogen peroxide and separating the metal-rich liquid for further processing. Although it is a lengthy process, it is highly efficient and can recover 95% of the semiconductor materials for use in new solar modules, as well as 90% of the glass. The recycling of CdTe solar cells is able to produce very high purity tellurium available for use within the production of new solar cells.

2.3.5 Substitutes of metals used in PV cells

Currently, R&D in thin film PV production focuses on minimizing the thickness of the material layers in CIS and CIGS PV cells as well as replacing those materials with "endlessly" available materials such as Kesterite (e.g. Cu2ZnSn(S, Se)4)).[92] Kesterite PV cells use common, abundant elements and are produced using inexpensive nanoparticle- and spin-coat-based "printing" techniques. However, kesterite PV cells are probably yet to gain a remarkable market share over the next few years.[93]

The projected gallium demand comes from photovoltaic cells based on the CIS/CIGS technology, where it is used directly as an absorber of

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[90] Moss et al (2011).
[91] Moss et al (2011).
[92] Buecheler (2012).
[93] Johnson (2010).

sunlight. Substituting gallium in this light-absorbing compound has not been discussed widely. Gallium only makes up a small fraction of the CIS/CIGS compound. Further lowering the fraction of CIGS could be a way to reduce gallium content.[94]

CIS/CIGS is the only technology which uses indium directly as an absorber of sunlight, while a-Si and CdTe only involve the use indium if the substrate- and cover-glass is ITO glass. Substituting indium in the CIS/CIGS technology has not been discussed. Substituting ITO-glass in all photovoltaic applications seems to be the single most important measure to reduce the use of indium. Substituting ITO-glass may not be that difficult, since there are already alternatives such as SnO2 (used by the largest CdTe manufacturer First Solar) and ZnO:Al (used by a wide range of CIS/CIGS manufacturers).[95]

Selenium makes up about 50% of the CIS/CIGS compound weight and is therefore a crucial component in the technology. Selenium is used directly as an absorber of sunlight. Substituting selenium in this light-absorbing compound has not been discussed widely.[96]

Tellurium demand comes from photovoltaic cells based on the CdTe technology, where it is used directly as an absorber of sunlight. Substituting tellurium in this light-absorbing compound has not been discussed widely.[97]

As described above the possibilities of substituting gallium, selenium and tellurium in photovoltaic cells is poorly studied, and currently no satisfactory substitutes are known. Fortunately, these elements are only used in CIS/CIGS (gallium and selenium) and CdTe (tellurium) photovoltaics, leaving several other technology options. The best alternative to CdTe and CIS/CIGS with regard to technology characteristics seems to be multi-junction amorphous silicon - a technology that is very tolerant to high temperatures and also performs very well in low-light conditions.[98]

2.4 Summary of metals used in electric vehicles and solar panels

Metals used in electric vehicles and solar panels are presented in Table 2.3. Rare Earth Metal use is particularly characteristic in electric vehicles whereas solar panels depend more on the use of specialty metals. Specialty metals are typically present in industrial and consumer products in small

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[94] European Parliament (2012).
[95] European Parliament (2012).
[96] European Parliament (2012).
[97] European Parliament (2012).
[98] European Parliament (2012).

amounts, but for their specific physical and chemical properties.[99] More detailed information per metal is presented in Annexes 2 and 3.

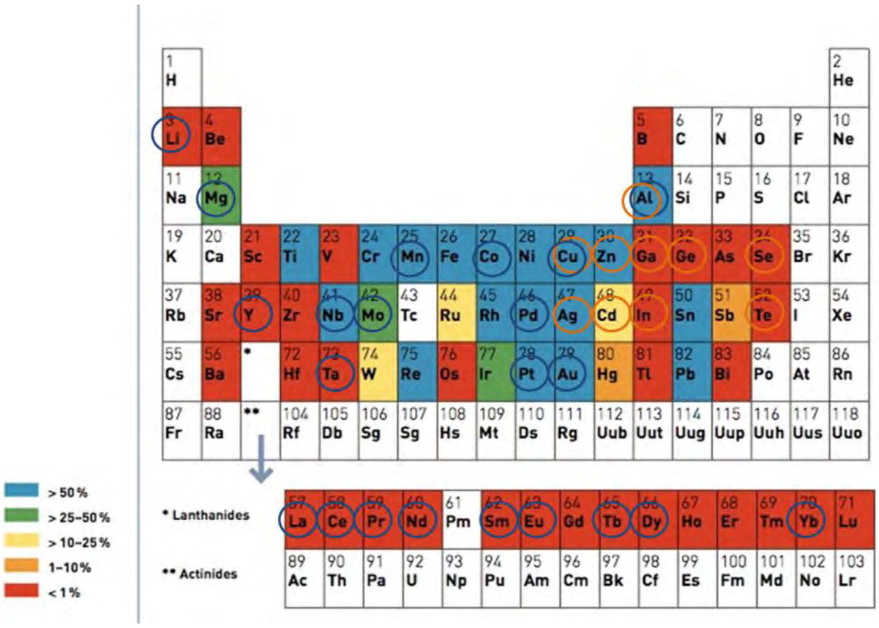
Table 2.3 Metals used in electric vehicles and photovoltaics

Metal	REM	EVs	PVs	Most common use[100]
Cerium (Ce)	x	x		Cerium is used largely as a catalyst
Cobalt (Co)		x		Cobalt's major uses are in superalloys, catalysts, and batteries
Dysprosium (Dy)	x	x		Dysprosium is used in magnets
Europium (Eu)	x	x		Europium is used as a phosphor
Gold (Au)		x		Most gold is used in jewelry, but some in electronics
Lanthanum (La)	x	x		Lanthanum is usually employed as a battery constituent
Lithium (Li)		x		Lithium's major use in batteries
Magnesium (Mg)		x		Magnesium is used in construction and transportation
Manganese (Mn)		x		Manganese is present at 0.3–1.0% in nearly all steels
Molybdenum (Mo)		x		Molybdenum is employed in high-performance stainless steel
Neodynium (Nd)	x	x		Neodymium is used in magnets
Niobium (Nb)		x		Niobium is used in high-performance stainless steels
Palladium (Pd)		x		Palladium's major use is in auto catalysts
Platinum (Pt)		x		Platinum's major use is in auto catalysts
Praseodynium (Pr)	x	x		Praseodynium is used in glass manufacture and magnets
Samarium (Sm)	x	x		Samarium is used in magnets
Tantalum (Ta)		x		Tantalum's principal use is in capacitors in electronics
Terbium (Tb)	x	x		Terbium is used in magnets
Yttrium (Y)		x		Yttrium is used as a phosphor
Aluminium		x	x	Aluminium is used principally in construction and transportation
Copper (Cu)		x	x	Copper sees wide use in conducting electricity and heat
Indium (In)			x	Indium's principal use is as a coating in flat-panel displays
Cadmium (Cd)			x	The principal use of cadmium is in batteries (85%) and in pigments (10%)
Gallium (Ga)			x	Gallium's principal use is in electronics: Ics, LEDs, diodes, solar cells
Germanium (Ge)			x	Germanium is used in night vision (infrared) lenses (30%), PET catalysts (30%), fiber optics, and solar cell concentrators
Selenium (Se)			x	Selenium is employed in glass manufacture, manganese production, LEDs, photovoltaics, and infrared optics
Silver (Ag)		x	x	Silver's principal uses are in electronics, industrial applications (catalysts, batteries, glass/mirrors) and jewelry
Tellurium (Te)			x	Tellurium's uses include steel additives, solar cells, and thermoelectrics
Zinc			x	Zinc's major use are in cans and solders

Examining the used metals and the end-of-life-recycling rate (EOL-RR) of these metals (Figure 2.9), it can be concluded that the recycling rate of the majority of metals used in electric vehicles and solar panels is very low.

[99] UNEP (2011a).
[100] UNEP (2011a).

Figure 2.9 End of life functional recycling[101] rate (EOL-RR) for sixty metals[102] and metals used in solar panels and electric vehicle (orange circles = solar panels, blue circles = electric vehicles)



Less than 1% of REMs are recycled from old scrap, mainly from old magnets. At current recycling cost level it is cheaper to buy newly manufactured magnets than to reprocess the scrap material. Another key challenge is that the scrap materials end up in generic scrap metal waste streams. Furthermore, large quantities of permanent magnets used in electric vehicles will not enter the waste stream for several years to come. A larger volume and more immediate opportunity in the waste stream exist in recycling the magnets contained within hard disc drives. [103] More effective recycling collection and sorting systems would need to be developed for both electric vehicles and PVs to reduce environmental impacts in the raw material and end of life phase, and improve sustainability of the whole supply chain.

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[101] Functional recycling is that portion of end-of-life recycling in which the metal in a discarded product is separated and sorted to obtain recyclates that are returned to raw material production processes that generate a metal or metal alloy.

[102] UNEP (2011a).

[103] Moss et al (2011).

3. Addressing sustainability along the supply chain: examples of initiatives, policies and schemes

This chapter presents initiatives that address environmental and social impacts of the use of metals both in the raw material and end-of-life stage. The list is not intended to be exhaustive but to provide interesting examples and information for companies and other actors working in different stages of the supply chain.

3.1 Sustainable mining and supply chains

3.1.1 International initiatives

Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development[104]

The Intergovernmental Forum is the institutional framework for the Global Dialogue on Mining/Metals and Sustainable Development which was one of a number of Partnership Initiatives launched at the World Summit on Sustainable Development in Johannesburg, South Africa, in 2002. It is a voluntary initiative by national governments with an interest in mining to work collectively to advance priorities identified for the sector in the Johannesburg Plan of Action. The Forum is the only global policy forum for the mining/metals sector with the overarching objective to enhance capacity for the overall governance in the sector.

The International Council on Mining and Metals (ICMM) [105]

ICMM was established in 2001 to improve sustainable development performance in the mining and metals industry. ICMM brings together 21 of the world's leading mining and metals companies with interests at over 800 sites in 62 countries across the globe as well as 31 national and

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[104] www.globaldialogue.info
[105] www.icmm.com

regional mining associations and global commodity associations. ICMM serves as an agent for change and continual improvement on issues relating to mining and sustainable development. Member companies have made a public commitment to improve their sustainability performance and are required to report against their progress on an annual basis.

Framework for Sustainable Mining[106]

The Framework for Responsible Mining is a joint effort by non-governmental organisations, retailers, investors, insurers, and technical experts working in the minerals sector. It outlines environmental, human rights, and social issues associated with mining and mined products. The Framework explores state-of-the-art social and environmental improvements, providing recommendations for various different actors in the public and private sector as well as non-governmental organisations and civil society groups. The "Framework for Responsible Mining" -document aims to provide a well-researched and thoughtful analysis of the key issues that should be addressed when defining "responsible mining."

OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-affected and High-risk Areas[107]

The OECD[108] Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas provides management recommendations for global responsible supply chains of minerals to help companies to respect human rights and avoid contributing to conflict through their mineral or metal purchasing decisions and practices. The Due Diligence Guidance is for use by any company potentially sourcing minerals or metals from conflict-affected and high-risk areas.

Communities and Artisanal & Small-scale Mining (CASM)[109]

The Communities and Small-scale Mining (CASM) initiative was launched in 2001, in response to a critical need for integrated, multi-disciplinary solutions to the complex social and environmental challenges facing artisanal & small-scale mining (ASM) communities, and improved coordination between those working in this sector. CASM is a global networking and coordination facility with a stated mission to "reduce poverty by improving the environmental, social and economic performance of artisanal and small-scale mining in developing countries". CASM is currently chaired by the UK's Department for International Development and is housed at the World Bank headquarters in Washington, D.C.

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[106] www.frameworkforresponsiblemining.org

[107] www.oecd.org/daf/internationalinvestment/guidelinesformultinationalenterprises/mining.htm

[108] Organisation for Economic Cooperation and Development.

[109] www.artisanalmining.org/casm/

GRI (Global Reporting Initiative): Mining and Metals Sector Supplement[110]

The Global Reporting Initiative (GRI) is a non-profit organisation that promotes economic, environmental and social sustainability. GRI provides all companies and organisations with a comprehensive sustainability reporting framework that is widely used around the world. GRI's Sustainability Reporting Guidelines include a specific Mining and Metals Sector Supplement (MMSS) for organisations in the sector. It includes the original Guidelines, which set out the Reporting Principles, Disclosures on Management Approach and Performance Indicators, and key issues for companies in the mining and metals sector to address issues such as:

- Biodiversity management and ecosystem services.
- Community consultation.
- Indigenous People's rights in exploration phase.
- Number and handling of disputes related to land.
- Resettlement of local communities.
- Closure plans of mines.
- Programs and progress relating to materials stewardship.

Since 31 December 2011, all GRI reports published by organisations in the mining and metals sector must use the Mining and Metals Sector Supplement regardless of their size, location, and activities (Level A).

UN Global Compact: Supply Chain Sustainability guidance

The UN Global Compact is a strategic policy initiative for businesses willing to commit to ten universally accepted principles in the areas of human rights, labour, environment and anti-corruption. Since many companies lack the knowledge or capacity to effectively integrate the principles into their existing supply chain programmes and operations, the Global Compact and partners have developed guidance on how to take a more proactive approach to integrate the Ten Principles into supply chain management practices. Guidance material includes:[111]

- An online tool intended to help companies to self-assess their approach to supply chain sustainability.
- Practical guides and reports for supply chain sustainability and fighting corruption.

[110] www.globalreporting.org/reporting/sector-guidance/mining-and-metals/
[111] www.unglobalcompact.org/Issues/supply_chain

- A website providing information on initiatives, resources and tools to assist companies in developing more sustainable supply chains: http://supply-chain.unglobalcompact.org/

Electronic Industry Citizenship Coalition (EICC) [112]

The EICC is a coalition of the world's leading electronics companies working together to improve efficiency and social, ethical, and environmental responsibility in the global supply chain. EICC membership is open to electronic manufacturers, software firms, ICT firms, and manufacturing service providers, including contracted labour, that design, market, manufacture and/or provide electronic goods or other materials or services to ICT firms (including e.g. technology providers for the hybrid and electric vehicle sector).

3.1.2 Government-level initiatives

US law on conflict minerals

On August 22, 2012 the U.S. Securities and Exchange Commission (SEC) voted to implement Section 1502 of the Dodd-Frank Wall Street Reform and Consumer Protection Act. Section 1502 relates to the use of conflict minerals and requires all publicly traded companies that manufacture consumer products containing gold, tantalum, tin or tungsten to trace the origin of these minerals and disclose whether or not they were mined in the Democratic Republic of Congo or selected surrounding countries, where human right abuses occur.[113] It is estimated that the rule will affect around 6000 companies in sectors such as automotive, electronics and telecoms, which are users of the elements.[114]

Although the so-called conflict minerals are not used in a large extent in electric vehicles and photovoltaics, the rule demonstrates an example of legislation and policies, which affects companies' supply chain management and reporting to reduce negative social impacts caused by metal extraction.

Finland seeking to become a leading country on sustainable mining

In a round table meeting between the Prime Minister of Finland, Minister of Economic Affairs, Minister of the Environment, Minister of Labour, senior executives of mining and technology companies and other invited senior officials, a joint objective was adopted in Helsinki on October 24, 2012 to make Finland the leading country on sustainable mining. The position paper was assigned by the Strategic Programme for Cleantech

[112] www.eicc.info

[113] U.S. Securities and Exchange Commission (2012).

[114] Snell (2012).

of the Government of Finland. Finland aims to combine environmental values and mining activities by developing technologies and the environmental know-how of companies. The round table agreed to continue the dialogue between stakeholders and work towards a joint vision for 2030. A series of meetings will be organized to develop an action plan towards sustainable mining 2030.[115, 116, 117]

Currently, Finland is a producer of chrome, copper, cobalt, gold, nickel, palladium, platinum, silver, sulphur, uranium and zinc. In addition, there are mining operation planned for niobium, phosphorus and lithium.[118] These include minerals also used in electric vehicles and photovoltaics. Therefore, Finland could be potentially a more sustainable source country for the metal needs of cleantech companies if metal processing is increasingly carried out in Finland.

Swedish Mineral strategy

As a response of the EU Raw Material Initiative recommendation, the Swedish government is preparing a mineral strategy during 2012. The strategy aims at long-term and sustainable use of Sweden's mineral resources. The work is being led by the Ministry of Enterprise, Energy and Communications in cooperation with other ministries, and is assisted by The Geological Survey of Sweden (SGU). In addition, regions, education institutions, county administrative boards, businesses, civil society and other relevant actors are providing input for the work through dialogue meetings. The strategy will be presented early 2013.[119]

Sweden is currently one of the EU's leading producers of ores and metals. It is, for example, the biggest producer of iron ore in the EU area. In addition, Sweden produces copper, gold, lead, silver and zinc.[120]

3.2 Recycling schemes, policies and actions

3.2.1 ELV Directive – End of Life Vehicle Directive[121]

The European Directive on the treatment of End-of-Life Vehicles (ELV) was adopted in October 2000. The objective of the ELV Directive is to prevent waste from end-of-life vehicles and promote the collection, re-use and recycling of their components to protect the environment. The

[115] Gaia (2012).
[116] Ministry of Employment and the Economy (2012).
[117] Invest in Finland (2012).
[118] Aaltonen et al (2012).
[119] Ministry of Enterprise, Energy and Communications (2012a & 2012b).
[120] SGU (2012).
[121] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32000L0053:EN:NOT

Directive sets clear quantified targets for reuse, recycling and recovery of vehicles and their components and pushes producers to manufacture new vehicles also with a view to their recyclability. The rate of re-use and recovery must be increased to 85% by average weight per vehicle by year 2006 and to 95% by 2015. According to the directive, Member States must set up collection systems for end-of-life vehicles and ensure that all vehicles are transferred to authorised treatment facilities.

3.2.2 WEEE Directive – PV recycling becoming mandatory[122]

The WEEE Directive (Directive on Waste Electrical and Electronic Equipment) regulates the appropriate treatment of end-of-life products. The directive requires that manufacturers and importers of electronic and electrical equipment ensure the take-back and recycling of their discarded end-of-life products in Europe. The first and original (2002/96) WEEE Directive dates from 27 January 2003 and was amended in 2003 and 2008. In 2012, the directive was amended again and now includes mandatory recycling of PV solar modules. The new WEEE Directive was published in the Official Journal of European Union on 24 July 2012 and entered into force on 13 August 2012. It shall be transposed into national laws by 14 February 2014.[123, 124]

The Directive asks producers to take back used products – without charge to consumers – and to recycle them. According to the directive, manufacturers and importers operational on the European market need to ensure the proper collection and recycling of their end-of-life products, and related financing. They may choose to fulfill their obligations either individually or by joining a collective scheme. The WEEE Directive encourages the use of existing infrastructure and industry-wide initiatives such as PV CYCLE (see 3.2.3). Collection and recycling has to be free of charge for the end user or any other person disposing of electronic or electrical equipment. Also, manufacturers and importers of these products need to register in each EU Member State that they operate in and report their country-specific sales figures to official bodies. In addition, the WEEE Directive requires a financial guarantee for future collection and recycling.[125]

According to the European Photovoltaic Industry Association, the inclusion of photovoltaic panels represents an important challenge for Europe's solar industry. The legislation provides no transitional period

[122] http://ec.europa.eu/environment/waste/weee/index_en.htm
[123] European Photovoltaic Industry Association (2012).
[124] pv magazine (2012a).
[125] PV CYCLE (2012).

for the inclusion of PV. This means that PV panel producers will now be obliged by law to ensure the collection and the recovery of end-of-life products. Producers may choose to fulfil their obligations either individually or by joining a collective scheme.[126] Under the EU directive, the producer can be the manufacturer or importer, or eventually, the seller or installer. It is at the discretion of each of the 27 Member States, who constitutes a producer. It is also currently open whether in the future old or broken photovoltaic modules are collected separately, or, for example, in communal recycling centers along with other electronic waste like computers and televisions.[127]

The PV industry calls on European policymakers to use the possibility foreseen in the Directive to set an individual collection target for PV panels. This would encourage separate collection of this product, whose composition and recycling techniques differ from those of other electrical and electronic equipment, such as TVs and radios. In order to reflect the very long lifetime of PV panels and the recent appearance of PV markets in Europe, an individual collection target for PV panels should be based on the quantities of end-of-life PV panels available. The PV industry considers the basis identified by legislators for the future overall collection target – the average weight of equipment sold in the three preceding years – to not suit the lifecycle and the market of PV panels. Therefore, policymakers should realise the unique nature of solar PV technology.[128]

3.2.3 PV CYCLE – take-back and recycling scheme for solar modules[129]

As PV modules had not been included in the European Waste Electrical and Electronic Equipment Directive (WEEE Directive) before the year 2012, a non-for-profit association, PV CYCLE, was founded in 2007 to ensure that its members' discarded end-of-life (EOL) PV modules are collected and processed in a sustainable and cost-effective way. In order to implement the PV industry's commitment to sustainable end-of-life management, PV CYCLE started as a voluntary industry initiative and aims to become a WEEE-compliant scheme.

PV CYCLE operates its take-back and recycling scheme for solar modules in all EU Member States as well as in the European Free Trade Association (EFTA) countries. The association has a pan-European network of hundreds of collection points, waste transporters and specialized recy-

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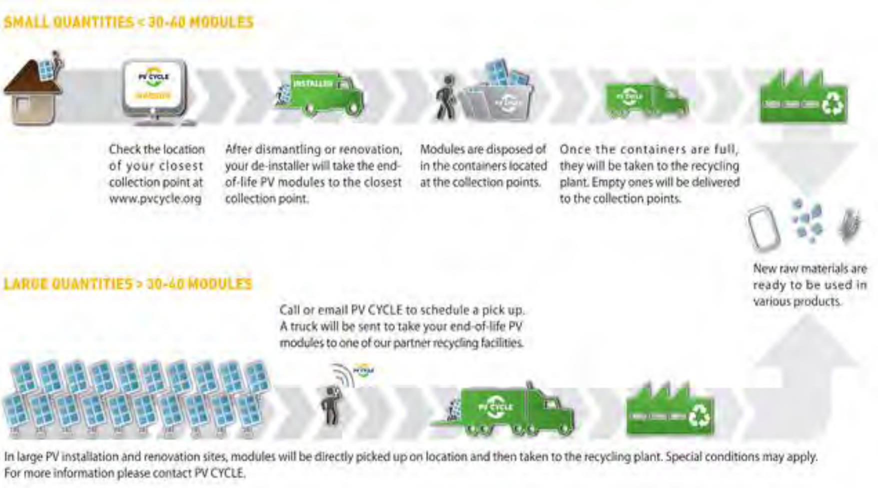
[126] European Photovoltaic Industry Association (2012).
[127] pv magazine (2012a).
[128] European Photovoltaic Industry Association (2012).
[129] www.pvcycle.org

cling facilities, which enables its members and their end customers a solution for collection and waste treatment. PV CYCLE represents approximately 90% of the European solar market today. The association is financed by the manufacturers and importers of PV modules in Europe.

Depending on the quantities that are being disposed of, PV CYCLE's collection service consists of two different paths for discarded end-of-life PV modules. Small quantities can be delivered to containers at collection points located at PV module retailers, wholesalers, and electrical installation contractors (Figure 4.1). Big quantities produced by large construction, renovation and demolition sites are taken care of by PV CYCLE's pick-up service.

Figure 4.1 PV CYCLE's collection service[130]



The service is free of charge for module owners and is open to anyone who would like to dispose of photovoltaic modules following a dismantling, demolition or renovation project. Those who can take advantage include electrical installation contractors, retailers, distributors, wholesalers, industrial end-users, producers, demolition companies, and households with PV modules. After collection, the modules are taken by PV CYCLE to recycling plants for dismantling and processing. The recycled materials can then be used in new products.

Out of the Nordic countries, PV CYCLE has currently a collection point only in Denmark.

[130] www.pvcycle.org

3.2.4 CERES – recycling organization for end-of-life photovoltaic modules[131]

CERES is a non-profit professional association headquartered in Paris. The association was founded in 2011 by professionals from the photovoltaic industry who were dissatisfied with the existing solutions and the lack of an effective and sustainable system for waste recovery. CERES has created a program for the collection and recycling of used modules and manufacturing scraps. The collection program claims to be the only organisation offering an entirely free take-back and recycling scheme for end-of-life photovoltaic modules in the European Union, and abroad when possible at a minimal cost. Waste can be deposited in certified collection points and will be recovered by recycling partners.

CERES complies with the WEEE Directive and works with national and international regulatory bodies on the implementation of new legal requirements. It also organises the registration and reporting on the behalf of its members, releasing them from administrative burden. During January–April 2012, CERES had collected 500 tons of photovoltaic modules and the target for the whole year is 1,500 tons.[132] Currently CERES has 113 members.

Out of the Nordic countries, CERES has currently a collection point only in Denmark.

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[131] www.ceres-recycle.org

[132] pv magazine (2012a).

4. Awareness and actions of Nordic cleantech companies

4.1 Survey carried out to Nordic cleantech companies

As a part of this study, a survey was conducted to Nordic cleantech companies. The survey examined the traceability of metals used in cleantech products, actions to reduce environmental impacts, substitutes and replacements, as well as cooperation with suppliers. The questions of the survey are presented in Annex 1.

The survey was targeted to cleantech companies in general to enable a broad target group. Answers were requested especially from raw material, component, technology and equipment providers as well as end-product manufacturers. In addition, the survey was requested to be forwarded to persons responsible for areas such as environment, quality, health, safety, sustainability, sourcing and/or R&D.

The survey was sent out in August 2012 to Nordic cleantech sector associations, who were asked to forward the survey to their members. Associations and organisations to which the survey was sent to included different Nordic wind power, solar power, and electric vehicle associations. In addition, the survey was sent to some cleantech companies directly, and information of the study and survey was also added to the web pages of the Finnish Environmental Forum for Business. As the survey was sent mostly to associations, which potentially forwarded the survey to their members, and not directly to companies, the exact number or companies, who received the survey is not known.

In total, only five companies responded to the survey despite that over 50 persons visited the survey website. This reflects that the topic seems to be difficult for cleantech companies. Many cleantech companies are still rather young, small and affected by a challenging financial situation. In addition, despite the anonymity of the survey, some may have been reluctant to share information especially related to R&D. The questions were simplified and sent out again to additional associations, but this did not make a big difference to the response level.

Although the response was low and in-depth analysis cannot be done either from a quantitative or qualitative perspective, some individual points are raised as an example of the awareness and actions of single cleantech companies.

Four of the companies had incorporated environmental and social issues in their companies in the form of example policy, code of conduct and/or supplier policy. Awareness of problems related to metal use in the supply chain varied among the companies. Three of the companies were very or somewhat aware and two were somewhat not aware of environmental and social problems related to metal use such as problems in the extraction phase, REM specific problems and the low recyclability of them. However, the awareness of problems related to metal use did not correspond directly to the companies' awareness of the origin of the metals used in their products. For example, a company which stated to be not very aware of problems related to metal use were aware of the origin of the metals they use and vice versa. Two companies were aware of the origin of the metals they used and one was working on the issue. These companies are probably examples of more advanced companies on these issues as they also decided to respond to the survey that most considered challenging to answer.

None of the companies had a reporting tool/system for tracing the metals used in their products although one of them was working on it by developing Green Supply Chain Management. However, three of the companies were taking actions to reduce environmental impacts of the metals used along their product's life cycle by, for example, improving the recyclability of their end-of-life products, preferring environmentally and socially responsible suppliers and partners, as well as improving material efficiency in their production. One company mentioned separately that they collect all end-of-life products for recycling.

Four out of the five respondents stated that they are have been searching for substitutes or replacements for metals used in their products. Main reason for this was the costs of metals and/or need for less energy-intensive or weight-saving solutions. Only one company expressed that one of the reasons for seeking for substitutes also related to the environmental and social problems of the raw material extraction of the metals they used. For this company also problems with the current and future availability of the metal(s) had an influence on seeking for substitutes or replacements. All the companies seeking for substitutes or replacements were working with external R&D partners such as universities, industry associations and research institutes.

Only one of the companies had a procurement policy for suppliers. This included a legal compliance statement and requirement of an Environmental Management System. One of the companies lacking a procurement policy expressed a need for proper tools to get right information from suppliers.

None of the companies were involved in associations or initiatives to improve traceability of metals, ensure responsible sourcing and/or improve recyclability and sustainability of their products' supply chain. This may be due to the fact that there are few existing in the cleantech sector. One of the companies requested for more information on the environmental impacts of the use of different metals to be able to address problems better.

4.2 Company case studies

In this chapter four different Nordic cleantech companies are examined as case studies. The aim of the case studies was to identify the environmental performance of the company and its use of critical and rare earth metals. In addition, substitutes and replacements sought by the company and recycling of its products are presented. Stakeholder requirements and expectations towards the companies concerning REMs/critical metals are also presented. As experienced with the survey, there were also challenges in finding suitable companies for the case studies. Especially the general PV market situation[133] in combination with the global economic situation formed challenges for the realization of the business case studies. Also in the EV sector, some companies initially planned as potential case study companies had filed for bankruptcy. However, four suitable case studies were eventually found. These were Volvo (Sweden), ABB Finland, Innotech Solar (Norway) and Beneq (Finland).

4.2.1 Volvo, Sweden

Company description

Volvo Cars (Volvo) was founded in Gothenburg in 1927 and is today a world leading car brand.[134] Volvo was until 1999 part of the Volvo Group, when it was purchased by Ford Motor Company. Since 2010 Volvo is an independent brand owned by the Chinese company Zheijiang Geely Holding Group.[135] In the Volvo Group, which Volvo belonged to until 2010, there was an environmental strategy which Volvo was part of. Volvo is now independent and is developing a strategy and an organisation by its own.[136]

Volvo has market presence in over 100 countries and a total of 19 494 employees worldwide. Volvo's market share of the global car market is 1–2%, and in 2010 the company increased its sales by 11.6%, reaching a total sales of 373,525 cars. USA, Sweden, Great Britain, China and Germany are Volvo's main markets. Volvo's growth strategy, due to the economic situation in Europe and US, is focused on developing markets where China is a focus market.[137]

Volvo has a strategy for electrification, which is an important part of their roadmap. The strategy includes both electric vehicles and hybrid

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[133] see e.g. REN21's Global Status report 2012 and various articles on http://www.renewableenergyfocus.com/

[134] Volvo (2012).

[135] Personal Communication, Volvo Cars, 2012-09-07.

[136] Personal Communication, Volvo Cars, 2012-09-07.

[137] Volvo (2012).

vehicles. The electric vehicles (EVs) and the plug-in hybrids (PHEVs) constitute a small part of the total cars sales, and 70% of the electric vehicles are purchased by companies.[138] Electric vehicles and PHEV is hence still a niche market for Volvo. China is an important market for Volvo and the Chinese government has an outspoken strategy to increase the number of electric vehicles on the road.[139]

Environmental performance and use of critical and rare earth metals

Cars are products with inherent negative impact on the environment and there is a high environmental consciousness at Volvo. The actions so far have been to decrease the fuel consumption and the weight of the cars. A change in attitude can be noticed among customers, who now demand products with less negative impact on the environment including lower fuel consumption.[140]

The main environmental impact of Volvo's products occurs in the driving phase. However, Volvo is also emphasising increased environmental performance regarding choice of material, the manufacturing process and the recycling phase. Since 2010, Volvo has an overall environmental strategy, which is followed up and updated once a year. Volvo has signed the United Nations Global Compact's ten principles regarding human rights, labour rights, environment and corruption. Volvo reports its social and environmental performance in accordance with the Global Reporting Initiative, G3 level B. Volvo has 450 suppliers providing components to Volvo and an additional 3,000 suppliers of other products and services. Approximately 70% of the value of the car is provided by suppliers.[141]

The manufacturing of a conventional car involves approximately 300–400 first tier suppliers. Approximately 2,500 items are used in one car, depending on the model. For EVs and PHEVs the majority of parts are the same as for a conventional car. For the specific parts used in electric vehicles the number of suppliers is less than ten and can be found all around the world. However, Volvo cannot reveal exactly how many and who they are due to business confidentiality.[142]

Volvo uses a system called International Material Data System (IMDS) where all parts that can be found in Volvo's cars can be traced. IMDS is used for collecting data on recycling, material, chemicals and allergy aspects of all the components. The system collects data throughout the supply chain, where Volvo's suppliers report and require data from its suppliers. The system relies on mutual trust between suppliers and Volvo. The system answers the questions of what materials the car contains

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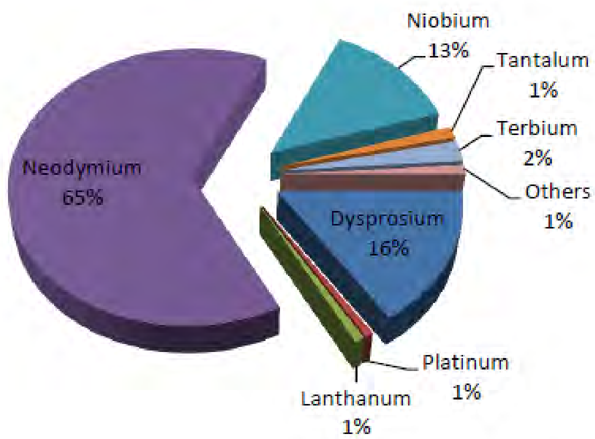
[138] Personal Communication, Volvo Cars, 2012-09-07.
[139] Personal Communication, Volvo Cars, 2012-09-07.
[140] Personal Communication, Volvo Cars, 2012-09-07.
[141] Volvo Personvagnar (2010).
[142] Personal Communication, Volvo Cars, 2012-09-07.

(Figure 4.1). It does, however, not trace the source of the raw material down to country or mine.

Figure 4.1 Summary of the results from the detailed analysis in terms of distribution by subsystem. Showing where the 24 materials' main masses where identified. The figure is a summary of all 4 analysed cars[143]

The mass distribution for potentially critical metals in a hybrid midsize car, medium specified is illustrated in Figure 4.2.

Figure 4.2 Mass distribution for materials in the Hybrid Midsize car, Medium-specified. Lithium is excluded for illustrational purposes[144]



143 Cullbrand and Magnusson (2011).
144 Cullbrand and Magnusson (2011).

The system is a joint-venture project developed during the 1990's as result of the legislation that was brought in demanding 95% of cars to be recyclable by 2015.[145] Large resources have been put in to building up and structuring of the system. At Volvo the production of a car will not be started until information about all materials has been delivered. The system contains hundreds of thousands of data sheets with a high level of details.[146]

Volvo used to conduct Life Cycle Assessments (LCAs) on their products around ten years ago, but are currently not conducting any LCAs. The conclusion from the analysis was that CO_2 emissions and weight are the most important environmental issues. Regarding the use of REM and other metals all suppliers have an interest of reducing the use of metals for cost reasons. This has been accentuated during the last years with the strong price increases of REMs.[147]

Volvo does not apply any specific sustainability criteria for REMs for its suppliers. Volvo buys components that contain REM, but does not purchase REMs as a raw material. Volvo does have criteria for, what they refer to as, direct material products.[148] Belgium, Germany, France, Great Britain and Sweden are where a majority of Volvo's suppliers are located. However, also Poland, Spain, Czech Republic, Italy and Turkey supply Volvo. In the relationship with suppliers Volvo has a code of conduct, which is communicated through the company's "Terms and Conditions" and "Social Responsibility Web guide". Volvo is also member of a network with the aim of developing a common sector approach for labour conditions in the supply chain.[149]

The relationships with suppliers are long-term. Usually it takes 2–3 years before the production starts, followed by production during five years. As Volvo guarantees its customers spare parts for a minimum of 15 years, Volvo's contract with the suppliers continues even after the production period. Volvo can cancel a contract with a supplier, but aims at avoiding a cancellation of a contract if is it possible as it takes 6–12 months to change supplier.[150]

At the purchasing department there is a routine for how suppliers should be handled, aiming at a long-term relationship and with a mutual interest of doing the right thing. Volvo has a system designed as a ladder with different steps a supplier can take for quality. The purchasing department is right now working on a similar system for environmental and social issues. According to Volvo, it is easier to work together with a

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[145] Cullbrand and Magnusson (2011).
[146] Personal Communication, Volvo Cars, 2012-09-07.
[147] Personal Communication, Volvo Cars, 2012-09-07.
[148] Personal Communication, Volvo Cars, 2012-09-07.
[149] Volvo Personvagnar (2010).
[150] Personal Communication, Volvo Cars, 2012-09-07.

supplier to raise its quality and environmental level, than to switch to another supplier. Volvo aims at developing its suppliers. An example of that is that 25 years ago Volvo started to require suppliers to implement a quality management system (ISO 9001); 20 years ago the demand of an environmental management system was raised. At Volvo the car is assembled, consisting of many components from many different suppliers, many of them larger than Volvo, which makes the sector unique. Low-wage countries are used to some extent, for example, production in Asia and Eastern Europe. Trade barriers play a great role, and create a willingness to manufacture and manage sales at the local market to avoid customs and high costs for logistic. Local production is important, as many components are heavy and expensive to move. Long lead-times imply high costs; especially for electrification as it is hard to predict the market and as the production volumes are low.[151]

Volvo acknowledges problems with REMs. The first step in identifying the area was to conduct a study of what kinds of REMs are present in Volvo's products. The study was conducted in collaboration with the Chalmer University of Technology in Gothenburg. The aim of the study was to find out the quantities of potentially critical metals used. The study will be the basis for further actions in decreasing and handling the negative environmental impacts from REMs. Regarding fuel and metals there are always geo-political risks that need to be handled, which is the case for lithium among other metals.[152]

Substitutes, replacements and recycling

Volvo does not have any particular projects addressing the issues of substitutes, replacements and recycling, but there are always plans to reduce the metal consumption as they are very costly. Generally, Volvo and its suppliers are working on decreasing costs. The availability of recycled metals is low, which means supply drives the use. Palladium can be recycled, as well as magnesium, steel and aluminium. However, the recycling of the materials does not decrease the costs for Volvo. Lithium-ion batteries will not be in the recycling systems in large volumes for the next 15 years. Smaller components in Volvo's cars are recycled through Elkretsen (a Swedish network for electronics recycling).[153]

Volvo does not do any recycling themselves, but in cooperation with other actors. The demands for recycling of vehicles in general are high, 85% of the material content. In a few years the demand for recycling will increase up to 95%. For the EVs and PHEVs the recycling rate of 95% recycling applies. There are general approaches in the sector for recy-

[151] Personal Communication, Volvo Cars, 2012-09-07.
[152] Personal Communication, Volvo Cars, 2012-09-07.
[153] Personal Communication, Volvo Cars, 2012-09-07.

cling, but the cooperation takes place with local actors in each country. Volvo has, what is referred to in Swedish legislation, Producer Responsibility. This implies that Volvo should provide customers with facilities for recycling within 50 km. The legislation of Producer Responsibility applies to all European markets. In Japan and China the legislation is similar to the European legislation, while the U.S. has not come as far.

According to Volvo, legislation is what is needed to increase the recycling rates, as the market incentives are not strong enough for recycling rates of 95%. Specific for EVs and PHEVs there are different systems in place for recycling of batteries in the sector. Volvo has yet not decided on how this system is going to be designed, but it is going to be part of their responsibility. Toyota has designed a system where they take the batteries back, while Renault has another system where the customer rents the batteries from Renault based on a cost per 100 km.[154]

The barrier is to recycle material that has no or very little value, such as plastics. For plastics it is hard to find a suitable are for use of recycled material. For Volvo it is possible to adapt design to recycling demands, if this is judged necessary for reaching the high recycling demands. One barrier for recycling of REMs is that they are used in very small amounts in many different parts of the car, which makes it hard to find a cost efficient recycling method. Customer demand is not a driving factor in recycling; rather the customer assumes that the car can be recycled. Another way to look at it is to say that cars have a reusable rate of 100%, as they have a long life-time as is re-sold several times in their life-time.[155]

Stakeholder requirements and expectations

There have been no demands from Volvo's stakeholders regarding REMs. Volvo says it takes a large and broad responsibility in the area of environment and that this does not imply any extra costs. It is also a dilemma, where different factors are weighted and turned into a decision. The decisions are complex, but environmental issues have a high priority. Volvo is building up an organisation for environmental issues. Volvo's focus, however, is not to save the world, but to increase the sales of EVs and PHEVs. Volvo cannot take responsibility for everything, but makes sure to be in context where they can make a difference in society. Volvo did, for example, participate in the discussions of Stockholm +40 and collaborates with the City of Gothenburg in city planning.[156]

In the U.S. the legislation on conflict minerals has been on the agenda for the American car industry, but as Volvo is not a U.S. limited company the legislation does not apply to Volvo. However, Volvo oversees what is

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[154] Personal Communication, Volvo Cars, 2012-09-07.
[155] Personal Communication, Volvo Cars, 2012-09-07.
[156] Personal Communication, Volvo Cars, 2012-09-07.

happening in the area, in case of a European legislation for conflict minerals. Volvo does not participate in any networks specialised in extraction of raw materials, but Volvo is participating in industry networks where environmental issues are a part. In Europe and USA, Volvo is part of several networks, ad-hoc groups and collaboration with universities. They cover very specific issues, but the representatives of Volvo do not know if REMs are covered in any of these initiatives.[157]

4.2.2 ABB Finland

Company description

ABB is one of the leading global providers of power and automation technologies to utilities and the industry. The company was formed in 1988 when Swedish ASEA and Swiss BBC were merged.

ABB employs over 135,000 persons in around 100 countries around the world. The company generated revenues of 38 billion USD in 2011 and net income of over 3 billion USD.[158] In the Nordic countries, ABB has around 18,500 employees in total.[159] ABB's Nordic Cleantech turnover is in hundreds of million euros and around 5% of the Nordic personnel work directly with Cleantech.[160]

One of the key Cleantech products by ABB Finland are the energy efficient permanent magnet machines. The permanent magnet approach can be used in electric motors that convert electrical energy to mechanical energy (see Figure 4.3).

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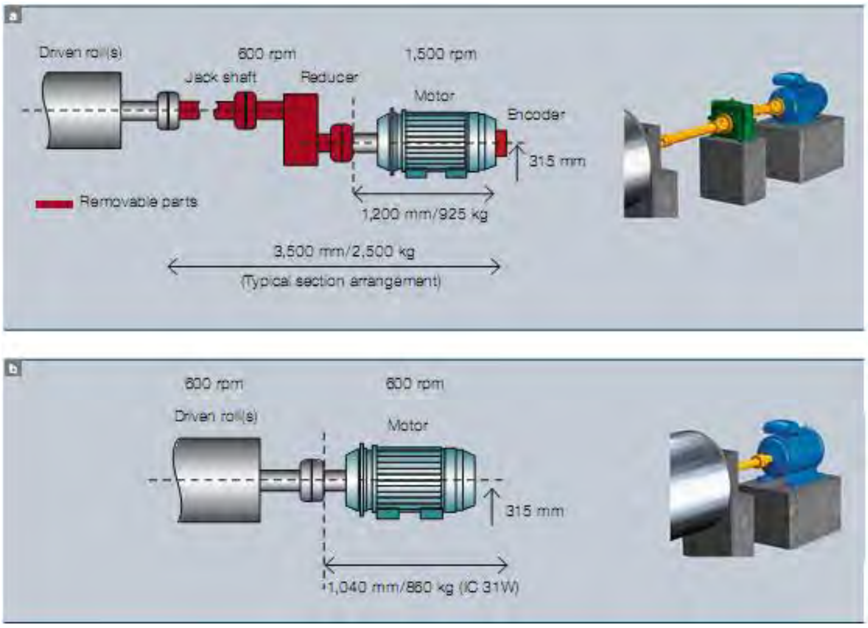
157 Personal Communication, Volvo Cars, 2012-09-07.

158 ABB, website www.abb.com, accessed 28 Sep 2012.

159 ABB, websites www.abb.dk, www.abb.fi, www.abb.no, www.abb.se, accessed 28 Sep 2012.

160 Personal communication, ABB Finland, 14 Sep 2012.

Figure 4.3 All electric permanent magnet motor (Exhibit b above) leads to fewer required parts, lower conversion losses, and better reliability when compared to conventional induction motor (Exhibit a)[161]

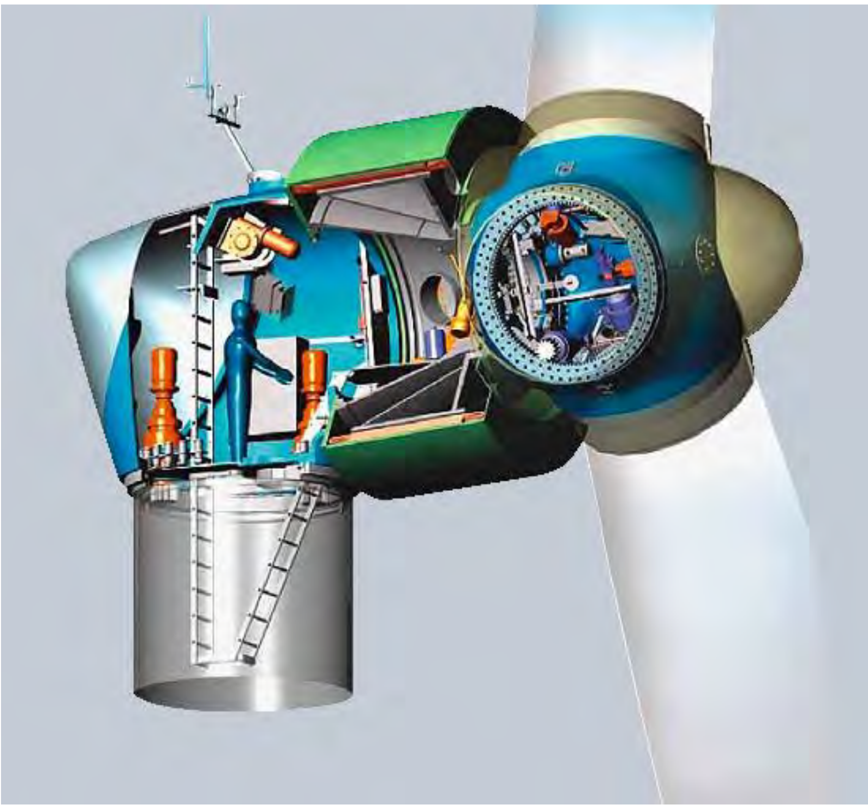


Environmental performance and use of critical and rare earth metals

The applications of permanent magnets motors and generators include industrial drives, marine propulsion systems and wind turbines (see Figure 4.4).

[161] Salo (2009).

Figure 4.4 A wind turbine with ABB's direct drive permanent magnet generator (green part)[162]



From sustainability point of view permanent magnet motors have various benefits over conventional induction generators. Permanent magnet generators weigh less and require less space than comparable induction generators. Permanent magnet generators do not require electricity to induce a magnetic field in the rotor, thereby reducing energy losses. In addition, permanent magnet generators allow elimination of several components, such as generator bruses, rotor winding insulation, and in the direct drive designs, the gearbox. However, some of these benefits are balanced by the need for larger diameter of the generators than in conventional designs and the need for extensive power electronics.[163]
One of the applications where ABB is promoting the use of permanent magnet generators is off-shore wind production. Off-shore wind-power needs to have high availability to be able to compete against other power generation forms. Direct drive permanent magnet generators reduce

[162] Salo (2009).
[163] U.S. Department of Energy (2010b).

the need for planned maintenance and are expected to increase the reliability of the wind turbines.[164]

The magnet ABB uses in its wind generator application is NdFeB magnet, i.e. Neodymium (Nd), Iron (Fe), Boron (B) magnet. Large scale NdFeB applications have become more attractive after the prices of magnets have dropped by around half after year 2000. Permanent magnets form a significant part of the manufacturing costs. For a large 2 to 4 MW direct drive wind turbine permanent magnet generator, the cost of magnets makes a considerable share of the total material costs of the generator.[165]

ABB is aware of the materials used in their products. In addition to neodymium, the critical rare earth metals in the permanent magnet motors and generators are dysprosium and cerium.[166] The company is also very aware of the potential issues in the supply chain of these metals. ABB is aware of the origin of the metals the company uses and has reporting in place for tracking the metals used in their products.

ABB is taking actions to reduce environmental impacts of the metals used along their product's life cycle. The company prefers environmentally and socially responsible suppliers and partners. They are also working on to improve material efficiency in their production, and providing their users with information on the energy efficient use of their products.

Substitutes, replacements and recycling

Lower prices of rare earth metals have allowed the commercial use of permanent magnet solutions. The development is relatively recent, for example the magnetic material NdFeB was invented in 1980's.[167]

The rapid uptake in wind power production creates pressures for both the price and availability of raw materials needed in manufacturing of wind turbines. For these reasons, ABB is searching for substitutes or replacements for the rare earth metals. However, the detailed R&D implications are company confidential internal information.

Stakeholder requirements and expectations

As one of the largest conglomerates in the world, ABB has numerous stakeholders. The company engages these various stakeholders around the globe on sustainability.

ABB is a member of numerous associations and initiatives in the area of sustainability. These include Global Reporting Initiative, UN Global

164 Salo (2009).
165 Salo (2009).
166 Personal communication, ABB Finland, 14 Sep 2012.
167 Sagawa et al (1984).

Compact Initiative, and Global Business Initiative[168] on Human Rights where ABB belongs to the leading core group of companies. Many of the initiatives that ABB follows include general elements for sustainability and environmental protection. However, there are no associations or initiatives that focus specifically on e.g. improving the traceability of minerals, ensuring responsible sourcing, and improving recyclability.[169]

ABB is keeping track of suppliers throughout the supply chain, and assess the environmental performance of suppliers. Environmental and social issues are incorporated in the company's procurement policy and other internal instructions.[170] In many countries, ABB is working with its suppliers to improve their sustainability performance. For example, in 2011 held supplier audits in China, India and Mexico.[171]

The most frequent discussions involved customers and suppliers, as well as ABB employees. In 2011, the most common themes in the discussions were ways of improving customers' energy efficiency, and strengthening suppliers' understanding of ABB's environmental, labour and health and safety requirements. In addition, the company met with government representatives, unions, NGOs, media representatives and academics at a national and corporate level.[172]

ABB has recognized that stakeholder engagement on sustainability issues is becoming increasingly important from strategic and business points of view. The company has adopted Sustainability Strategy 2015+, where one of the tasks is to improve stakeholder engagement by the end of 2013.[173]

4.2.3 Innotech Solar, Norway

Company description and business model

Innotech Solar (ITS) uses an innovative processing technology, where re-used cells are transformed through an optimization process into highest quality productive solar cells, modules, and power plants with a minimum of additional energy. Such optimized crystalline solar cells are embedded in panels and branded as ITS products.[174]

The idea of a new market niche originated in both the fact of rapid PV market growth and that some cells are eliminated from the value chain not meeting the high quality requirements to be used in modules. The value proposition is built on high quality with first-class modules and

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168 www.global-business-initiative.org

169 Personal communication, ABB Finland, 14 Sep 2012.

170 Personal communication, ABB Finland, 14 Sep 2012.

171 ABB (2012).

172 ABB (2012).

173 ABB (2012).

174 Personal communication, ITS, 14 Aug 2012.

long warranties; service and closeness to the end-customer and a sustainable business model combining re-use /waste avoidance strategy with cell optimization.[175]

ITS focuses on high product quality. This is achieved by regular quality checks on production. Such checks include among others hot-spot prevention through multiple thermal imaging scans on cell-level, long-term tests by independent institutes based on Standard Test Conditions (STC) or weak light, degradation measurement as well as wet leakage tests. Modules are salt mist and ammonia resistance and certified as per International Electrotechnical Commission (IEC) and Underwriter Laboratory (UL). Consequently ITS is working with the world's major cell producers to get access to volumes of non-standard solar cells.[176]

Innotech Solar (ITS) has also developed a 72-cell solar module that is made using re-processed solar cells and has an excellent carbon footprint as a result. The modules are larger than customary 60-cell modules and generate a higher yield. In fact, around 20% fewer modules are needed to achieve the same power yield, meaning that the costs for support frames and installation are lower. Innotech Solar analyses and optimizes cells from various manufacturers and has a production capacity in excess of 160 MWp.[177]

Innotech Solar was founded in 2008 by leading executives of Norwegian solar pioneer REC Solar, latter a vertically integrated company covering whole value chain as producer of poly-silicon and wafer, over modules producer to PV project development. In 2009 ITS established in Munich, Germany an office as a market interface to the global headquarters for the sales department, taking into account that Germany was already then the biggest PV market in the world. One year later ITS built a new cell-optimization factory in Halle, Germany in order to satisfy the increased market demand. In 2011, the expansion to the US with a sales subsidiary in Vista, California took place to establish sales in North and Latin America. In the first half of 2012 a new CEO was appointed to focus on growth, to improve processes and decrease costs. [178]

Environmental performance and use of critical and rare earth metals

ITS has certified its production locations in Germany according to Environmental Management Standard ISO14001. In summer 2012 ITS has been certified based on an integrated management approach by combining quality (ISO 9001), environment (ISO 14001) and safety (OHSAS 18001).[179]

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[175] Innotech Solar (2012) and www.innotechsolar.com, accessed 14th Aug 2012.
[176] Innotech Solar (2012).
[177] pv magazine (2012b).
[178] Innotech Solar (2012) and www.innotechsolar.com, accessed 14th Aug 2012.
[179] Personal communication, ITS, 14 Aug 2012.

The input materials for ITS's modules are cells, otherwise declared as waste or used for cheap low-quality and low-efficiency modules. The origin of these re-used cells is from different world's major cell producers. These are all silicon-based cells and consequently REM and critical metals are not an issue. ITS is tracking the origin of these cells as well as managing a hazardous material substance database as part of the integrated management system. ITS's production process is purely mechanical and does not imply any chemical treatment process. A challenge is to get detailed production information on the cells. LCA are not done yet but carbon footprint analysis over the whole value chain is in preparation.[180]

Substitutes, replacements and recycling

The re-use and waste avoidance is part of ITS business model focusing on multi-crystalline silicon solar cell modules only. Normally these types of module have an average energy payback period of about 1–1.5 years. By using cells, which are normally rejects, energy savings of up to 90% can be generated through an additional technical lifetime with net gains on energy produced. The energy payback period for these modules is between one and two month.[181]

Stakeholder requirements and expectations

The si-PV industry is well prepared concerning the recycling. So far the volumes have been not economic viable due to the fact of an emerging market. With a module life span of > 20 years old modules are coming now to the recycling market with economic interesting volumes.[182]

ITS is part of the European centre for the recycling of solar energy (CERES). It complies with the main principals of the WEEE Directive and works with national and international regulatory bodies on the implementation of new legal requirements.[183]

4.2.4 Beneq, Finland

Company description

Beneq offers enabling technology for PV companies to use scarce or critical resources more efficiently. Beneq business activity concentrates on equipment and technology for functional coatings, based on its experience to supply systems for research and industry. Its products are thin film coating equipment for industry and R&D with applications in two core technology areas: atomic layer deposition (ALD) and aerosol coat-

[180] Personal communication, ITS, 14 Aug 2012.
[181] Personal communication, ITS, 14 Aug 2012.
[182] Personal communication, ITS, 14 Aug 2012.
[183] Personal communication, ITS, 14 Aug 2012.

ing technology. Beneq's business model is to development and licensing equipment in these two technologies based on its Intellectual Property Rights IPR portfolio with more than 100 patent families including processes, equipment and applications.[184]

Beneq is a privately owned and venture capital funded company. Founded in 2005 Beneq is an application-driven thin film equipment provider. The market is cleantech and renewable energy industries, especially photovoltaics, flexible electronics and flat glass.[185]

Three relevant applications for the PV sector can be highlighted as follows:[186]

Transparent Conductive Oxide (TCO): A transparent conductive oxide coating, abbreviated TCO, is a doped metal oxide thin film predominantly used in optoelectronic devices, for example flat panel displays and photovoltaics (incl. inorganic and organic devices as well as dye-sensitized solar cells). Most TCOs are manufactured with polycrystalline or amorphous microstructures.

Surface passivation for c-Si: The PV industry today needs to increase conversion efficiency without jeopardizing the economic and technical feasibility of industrial production. A proven means to improve the efficiency of crystalline silicon (c-Si) solar cell wafers is surface passivation by atomic layer deposition (ALD). Passivation of the surface enhances the overall cell efficiency by prolonging the charge-carrier effective lifetime. Surface passivation by ALD is beneficial on both the front and rear surface of an n-type wafer.

Buffer Layer for CIGS: The atomic layer deposition (ALD) can be used to improve the efficiency of copper-indium-gallium-diselenide (CIGS) solar cells. ALD enables replacing the conventional cadmium sulphide (CdS) buffer layer with one with a higher band gap energy and light transmission, thus resulting in a more than 1 percentage point increase in unit efficiency. This is achieved by depositing a dense and conformal zinc oxysulphide Zn(OS) buffer layer. Using ALD simplifies production routines significantly reduces cost. Moreover, introducing cadmium-free buffer layers results in fewer loads on the environment and less stringent in-house material safety routines. ALD is a dry coating process, which means there are no excessive water handling, no toxic effluents and no need for waste water purification.[187]

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[184] Beneq (2012a).
[185] Personal communication, Beneq, 6 Sep 2012.
[186] Personal communication, Beneq, 6 Sep 2012.
[187] Beneq (2012b).

Environmental performance and use of critical and rare earth metals

Beneq serves as an enabler for PV companies. There are no relevant rare earth metals issues except those from electronic and electrical components in the thin film equipment. Beneq is a young company and has put in place all measures according the Health, Safety and Environment legal requirements. Governance structure is operational with environmental and work safety committees and with the documentation and the management system for the material safety data sheets.[188]

As part of their own R&D, Beneq collaborates very closely with clients' R&D department. This allows a joint equipment development and development of thin film process striving for reduction in use of critical and rare earth metals and substitution of those metals. So far clients do not order to integrate environmental aspect and life cycle assessments in the development process. Main reasons are financial barriers and trade-offs between environmental and technology improvements in the early stage of the R&D.[189]

Substitutes, replacements and recycling

The example of the application of atomic layer deposition in connection with CIGS PV technology illustrates very well to what extent technology and process wise substitution and replacements can be realized. The business model of Beneq focuses on the product improvement. These improvements include both reductions of critical and costly materials as well as the production process itself.[190]

Beneq is not involved in any recycling activities except for specific client query. The trend of more applications using rare earth metals and strong quantitative growth of clean and renewable technology will accentuate the need for solution strategies to reduce, reuse and recycle products. The company believes addressing these issues are important for the players in this sector and that there should be mandatory rules. New and more stringent environmental regulations will emerge and create incentives to improve the environmental performance of the PV companies.[191]

Stakeholder requirements and expectations

Beneq is now moving from a start-up into a growth phase company. Continuous improvement is a very strong part in the company culture and along this journey the own need and market needs for environmental performance will increase.[192]

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[188] Personal communication, Beneq, 6 Sep 2012.
[189] Personal communication, Beneq, 6 Sep 2012.
[190] Personal communication, Beneq, 6 Sep 2012.
[191] Personal communication, Beneq, 6 Sep 2012.
[192] Personal communication, Beneq, 6 Sep 2012.

5. Analysis

Cleantech companies seek to provide sustainable solutions
Cleantech companies try, by definition, to provide more sustainable alternatives to traditional products and services. However, the new technologies and materials needed to produce them can create conflicting objectives for the cleantech industry as some materials may have negative environmental impacts. An example of this from the automotive sector is the use of Rare Earth Metals (REMs) in electric vehicles. Electric vehicles are one of the most energy efficient solutions to reduce carbon emissions of transportation. However, electric motors and limited battery capabilities in current electric vehicles have increased the need for low weight materials. This in turn has increased the demand for suitable REMs and potentially critical metals.

REMs are part of cleantech technologies
Many REMs and critical metals are an integral part of the technical solutions or enabling technologies in many cleantech applications. Specific characteristics, for example in weight and electromagnetism, make REMs unique and create considerable benefits in commercial applications. Therefore, REM and related trade-offs have to be accepted as long as there are no substitutes with an overall more positive or less negative balance.

Relevance and materiality of REMs in cleantech subsectors varies
The use of REM and critical metals differ between the subsectors of cleantech both in terms of importance and quantity. The quantities used affect the magnitude of issues linked to the supply chain or recycling. For example in electric vehicles and wind power, rare earth and critical metals are used in key components such as in magnets of electric engines and batteries. In the majority of photovoltaic applications, the use of REMs is more limited and the quantities used are smaller.

Challenge of allocation of environmental impacts in the value chain
Increased focus on sustainability has created a relatively good general understanding of the environmental and social impacts of mining of metals and consecutive processing. However, there is insufficient information on how such impacts are specifically allocated to REMs and critical metals from a life cycle assessment perspective. For example, metals such as gallium or selenium are side products of zinc or copper mining. On the other, hand mining neodymium enables extraction of other side-products, such as iron and heavy metals.

One key issue is the traceability of raw materials. Invariably minerals and stones are mined by small artisanal miners and then distributed to trade houses via a string of agents. This makes traceability and accountability when it comes to social and environmental impacts particularly challenging.

Challenges to recycle REMs due to low quantities used

Recycling of REMs and critical metals are often not profitable because the substances are found in small quantities and in complex systems. Currently, REMs and critical metals are covered under the legislation of producers' responsibility. However, as the quantities are in many cases small, the metals might fall outside recycling rate requirements.

In other sectors there is a considerable drive towards closed loop production cycles and re-use rather than recycling. Companies strive to retain or even add value to end-of-cycle goods through, for example, upcycling or repurposing. In upcycling, value is added by for example using plastic bottles to build office furniture (Scandinavian Business Seating) or to develop fleece jackets (Norrøna). In repurposing, value is usually lost, or at best retained, but the material is used for other purposes such as Nike using ground running shoes as fill for synthetic turf or cushioning in children's playgrounds.

The current relatively high market prices of many minerals and issues such as supply security have resulted in a rise in urban mining. Companies try to extract latent value of REMs in goods that are at the end of their current life cycle (cradle-to-cradle). Norway is a global leader here, claiming to recycle almost 90% of its electronic waste.

Challenges for companies to maintain awareness on REM issues

Knowledge regarding environmental and social impacts of the use of critical metals and REMs is limited or even lacking completely. The amounts of materials used in many cleantech applications are small and often part of other enabling technologies. However, larger frontrunner companies have already addressed many of the issues regarding REM use, as seen for example in the cases of ABB and Volvo.

Key learnings gathered by such large companies are often publicly available as a result of increased transparency and disclosure requirements, especially through sustainability reporting. For small and medium-sized companies, limited resources often restrict their ability to keep informed of industry advancements.

So far limited information sharing mechanisms within the industry

The study did not reveal any networks, roundtables or other information sharing mechanisms in the area of REMs or critical metals.

Examples in other sectors include the Roundtable on Sustainable Palm Oil (RSPO). RSPO was established also partly to tackle the issue of traceability and to induce a continuous improvement process as a means of solving the environmental impact of palm oil production. The organisation has developed the RSPO certification scheme using the same traceability methodology as Utz applies to coffee, cocoa and tea. Unilever is for example deeply involved in the RSPO process. Examples in other industries include the Better Cotton Initiative, where companies like H&M and IKEA are involved, and the Kimberly Process for diamonds.

Stakeholder requirements and expectations not REM specific
Cleantech companies like other major manufacturers face increasing disclosure requirements from their stakeholders, and specifically from their investor community. Responsible companies following reporting systems such as the Global Reporting Initiative to report on how they are addressing sustainability issues in their organisations. However, there have been less specific requirements for REM specific information.

6. Conclusions and recommendations

Cleantech addresses ecological challenges of our times
Cleantech comprises of new technologies and business models that offer benefits for customers while providing solutions to global environmental challenges. Cleantech represents a diverse range of products, services, and processes, all intended to provide improved performance at competitive costs, to reduce or eliminate negative ecological impacts, and to improve the productive and responsible use of natural resources.

Cleantech technologies can increase the need for rare earth metals
Global scale environmental issues have created vast demand for cleantech applications, for example in carbon emissions reduction. Demand is being met with various cleantech applications and technologies. In turn, some of these new technologies increase the use of REMs. Nevertheless, the negative impacts related to REM use need to be considered in comparison to the benefits of cleantech technologies.

Cleantech companies are challenged to trace the materials they use
Traceability of REMs and critical metals and accountability for social and environmental impacts in their extraction is challenging. The metals are often procured through long supply chains and from regions with limited regulatory requirements for transparency. There is also insufficient information on how such impacts are specifically allocated to REMs and critical metals used from a life cycle assessment perspective.

Companies could be supported with information and tools
To mitigate the potential problems related to REMs and critical metals companies will need to develop their knowhow and procurement processes. The resource requirements for adequate development can become prohibitive, especially for small and medium-sized companies. In practice, sector wide guidelines or checklists could be developed.

Transparency as well as environmental, societal, and economic impacts over the whole life cycle of current and alternative metals used could be addressed. In the short-term, this can be accomplished through awareness raising activities and information sharing, and in the mid-term through further data gathering and research. The Nordic Council of Ministers and the Nordic governments could also use their influence to increase transparency and sustainable extraction in the countries of origin for REMs and critical metals.

Support could be funnelled through existing industry organisations. Specialist support on developing and following up on requirements to suppliers can be found through membership of organisations specialising in social and environmental compliance in the supply chain such as the Ethical Trading Initiative, Business Social Compliance Institute and the UN Global Compact's Supply Chain Sustainability Programme.

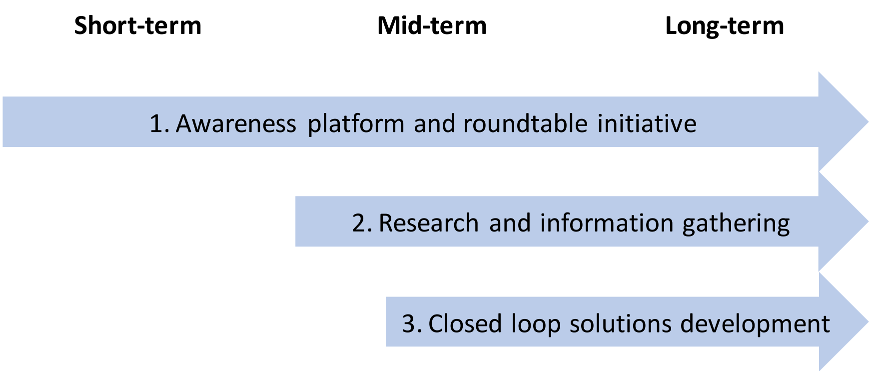
Long-term target to find closed loop solutions

Cleantech solutions are still under development, and they have been in use for only short periods of time and in limited quantities. As the use of cleantech technologies spreads, so does the importance of developing effective methods for re-using cleantech technologies and recycling materials.

Nordic Roadmap for more sustainable metals use

On the basis of this study, the recommendations to develop sustainable metal use in the Nordic area can be summarized as three initiatives presented in Figure 6.1.

Figure 6.1. Road map for more sustainable metals use in the Nordic area



#1 Awareness platform and roundtable initiative

Awareness on the sustainability issues with REMs and other critical metals use is low within the cleantech sector. On the short term, there is a need to raise awareness of the companies that there are potential issues and that they should consider also the supply chain effects of the metals they are using. Nordic countries and the Nordic Council of Ministries in particular could promote these issues as part of the other communication on sustainable business and environmental concerns.

One potential initiative is to establish an information sharing and collaboration roundtable for interested parties. The Nordic Council of Ministries could support the roundtable directly by providing financial or organisational resources for such initiative, or by supporting the establishment of the roundtable. It should be noted, that for the roundtable to work effectively, there has to be enough interested parties to participate to such initiative.

#2 Research and information gathering

The use of cleantech will increase as companies strive to develop effective solutions to meet global environmental challenges. To better understand and to enable the mitigation of the negative environmental and social impacts of REMs, further research and information on the impacts of metals use in the whole value chain is needed. Companies and research institutes have already jointly studied the metals use in some instances, but for many cleantech applications factual base is lacking.

Sustainable REMs and other critical metals use could prove to be a feasible theme for a Nordic research project. With a wider scope of sustainable supply chains there could be potential for a research program. Such research initiatives could be steered by NordForsk.

A lot of information is already available. It can be tried to put together in a more concise format through focused studies such as this one.

#3 Closed-loop solutions development

Long-term sustainable use of REMs and other critical metals will necessitate smarter and more advanced solutions than today's reliance on mining of primary materials.

As an alternative, there is at least in theory a lot of potential in the re-use of components and recycling of materials. A long-term goal would be closed-loop processes, where re-use and recycling completely replace the need for mining and new material intake to the process.

The concrete initiatives could include support for R&D&I activities in re-use and recycling of REMs and other critical metals in cleantech. The re-use and recycling R&D&I efforts should in addition be complemented by studies on the substitutes and alternative solutions. Nordic countries could commonly seek to position themselves as leaders in these even more sustainable cleantech solutions.

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8. Sammanfattning

Metaller i sina olika former, som används för olika ändamål, är en central del av den globala ekonomin och de har blivit allt mer viktiga. Metaller behövs även när vi skall övergå till en framtid med lägre koldioxid utsläpp och till en mer resurssnål ekonomi.

Gruv verksamheten och miljöstyrningen av metallutvinning har blivit mer hållbar under de sista 20 åren. Ett flertal projekt, initiativ och aktiva organisationer har tagit tag i frågor som omfattar gruvverksamhetens hållbarhet. Trots detta finns det mycket problem från social- och miljösynpunkt. Många gruvor orsakar spänningar inom samhällen och mellan samhällen. Gruvorna kan vara potentiella problem från säkerhets synpunkt både på lokal- och region nivå.

De som producerar slutprodukterna känner inte nödvändigtvis till de skadliga verkningarna som utvinning av råvaran eller de olika bearbetningsfaserna kan orsaka. En av de största utmaningarna som bolagen har är att ta reda på varifrån metallerna som används i deras produkter kommer. Metallernas leveranskedjor är komplexa och involverar ett flertal olika aktörer som t.ex. gruvoperatörer, handlare, raffinerare och tillverkare.

Den här studien, som har beställts av Nordiska Ministerrådets arbetsgrupp för hållbar konsumtion och produktion, gjordes för att man skulle få en klarare bild av leveranskedjorna av utvalda sällsynta jordmetaller (Rare Earth Metals (REMs)) och andra kritiska metaller, som används i cleantech lösningar inom speciellt biltillverkningsindustrin samt i tillverkningen av solpaneler.

Studiens målsättningar var följande:

- Studera leveranskedjan av sällsynta jordmetaller och andra kritiska metaller, som används inom bilindustrin samt inom tillverkningen av solpaneler, och miljöproblemen som är förknippade med dessa.
- Kartlägga de befintliga initiativen, politikåtgärderna och andra planer som fokuserar på miljöpåverkan av sällsynta jordmetaller och kritiska metaller.
- Kartlägga hur mycket cleantech bolagen i Norden känner till problemen som är förknippade med sällsynta jordmetaller och kritiska metaller, samt kartlägga initiativ, som har som målsättning att lösa de förknippade problemen.
- Presentera förslag på konkreta åtgärder för att lösa problem som är förknippade med metallerna och deras återvinning, samt att presentera en vägkarta för hållbar användning av metaller i Norden.

- Presentera klara och tydliga slutsatser och rekommendationer som kan användas som utgångspunkt för kommunikation och som kan tillämpas brett inom cleantech sektorn och inom andra sektorer.

Sällsynta jordmetaller används i cleantech applikationer på grund av deras unika kemiska, magnetiska och elektriska egenskaper. Trots deras namn, anses de inte vara sällsynta, men de har avsevärda miljöinverkningar under utvinnings- och bearbetningsfasen av råvaran.

Cleantech omfattar nya teknologier och business modeller som erbjuder fördelar till kunder och som erbjuder lösningar till globala miljöutmaningar. De negativa inverkningarna som förknippas med användning av sällsynta jordmetaller (REM) måste vägas mot de positive inverkningarna som cleantech lösningarna kan ha. I elfordon används sällsynta jordmetaller i många syften och applikationer. Som ett exempel kan nämnas de permanenta magneterna i bilarnas motorer. Användningen av sällsynta jordmetaller i solpaneler är mer begränsat, även om olika el komponenter i en viss omfattning kan innehålla sällsynta jordmetaller.

Att lösa spårbarheten av sällsynta jordmetaller och andra kritiska metaller och att kartlägga ansvaret för sociala och miljömässiga konsekvenser i deras utvinning, är en utmaning. Metallerna är ofta upphandlade genom långa leveranskedjor och från regioner med begränsade krav på öppenhet. Det finns inte heller tillräckligt med information om vilka av konsekvenserna av utvinningen av metallerna som kan tilldelas sällsynta jordmetaller och kritiska metaller när man ser på det från ett livscykelperspektiv. Även om leveranskedjan är lång, kan mycket göras för att se till att för-sörjningskedjan blir mer ansvarsfull och hållbar både i råvarufasen av försörjningskedjan och i slutet av livscykeln. Detta kan göras bl.a. genom att förbättra andelen återanvänd och återvunnen metall.

För att mildra de potentiella problemen som är förknippade med sällsynta jordmetaller och kritiska metaller, kommer företagen att behöva utveckla sina kompetenser och sina upphandlingsprocesser. Resurserna som krävs för en för adekvat utveckling kan bli för stora, särskilt för små och medelstora företag.

Cleantech lösningar är fortfarande under utveckling och de har varit i bruk endast i begränsad omfattning. Eftersom användningen av cleantech teknik sprids, så blir det också viktigare att utveckla effektiva metoder för återanvändning av cleantech teknik och för att återvinna material. För närvarande är återvinning av sällsynta jordmetaller och kritiska metaller ofta inte lönsamt, eftersom ämnena finns i små mängder och de används inom komplexa system. Att öka andelen återvunnen metall är viktigt när vi går mot en mer hållbar användning av metaller.

Återvinning av solcellsmoduler och material har redan diskuterats, och återvinning av solcellsmoduler blir obligatoriskt genom Europeiska Unionens Waste Electrical and Electronic Equipment (WEEE) direktivet. För sällsynta jordmetaller som används i elfordon, kommer återvinningskrav från de krav som ställs på producenterna. De kräver en viss återvinning för hela fordonet. Men eftersom mängderna sällsynta jordmetaller som används är relativt små, omfattas de inte nödvändigtvis av kraven för återvinning.

På basen av denna studie kan rekommendationerna till att utveckla hållbar metall för användning i Norden sammanfattas som tre initiativ:

1. Medvetenhetsplattform och initiativ till rundabordssamtal (kort sikt): Etablera system för att dela kunskap och initiera rundbordssamarbete för berörda parter. Nordiska Ministerrådet kan stödja rundabordssamtal direkt genom att allokera ekonomiska eller organisatoriska resurser för ett sådant initiativ, eller genom att stödja inrättandet av ett rundbords forum. De nordiska länderna kan dessutom använda andra kommunikationsinsatser för att öka medvetenheten om potentiella problem i leveranskedjan för sällsynta jordmetaller. I praktiken kan sektorsinriktade riktlinjer eller checklistor utvecklas.
2. Forskning och informationsinsamling (mellanlång sikt): Användning av cleantech kommer att öka eftersom företagen strävar efter att utveckla effektiva lösningar för att möta de globala miljöproblemen. För att bättre förstå och för att möjliggöra att lindrandet av de negativa miljömässiga och sociala effekterna av sällsynta jordmetaller, behövs ytterligare forskning och information om effekterna av hur metallerna används i hela värde kedjan. Hållbara sällsynta jordmetaller och användningen av andra kritiska metaller kan dra nytta av ett nordiskt forskningsprojekt eller program.
3. Utveckla slutna processer (lång sikt): Det finns, åtminstone i teorin, en stor potential för återanvändning av komponenter och återvinning av material. Ett långsiktigt mål skulle vara slutna processer, där återanvändning och återvinning helt ersätter behovet av gruvdrift- och intag av nytt material till processen. De konkreta initiativen kan omfatta stöd för forskning, utveckling och verksamhet för att befrämja återanvändning och återvinning av sällsynta jordmetaller och andra kritiska metaller inom cleantech sektorn.

Appendix 1:
Survey questions

A. Background questions

1. Title of respondent
2. Main cleantech areas of your company (multi-selections possible):
   - □ Agriculture
   - □ Air & Environment
   - □ Biomass, Bioenergy, Biofuels & Biomaterials
   - □ Building and Construction Materials
   - □ Carbon Technologies
   - □ Clean processing technologies
   - □ Energy Efficiency
   - □ Energy Storage
   - □ ICT, automation
   - □ Material Efficiency
   - □ Recycling & Waste
   - □ Smart Grid
   - □ Solar
   - □ Transportation
   - □ Water & Wastewater
   - □ Wind
   - □ Other, please specify? ________________________________
   - □ Cannot say
3. Turnover:
   - ○ Less than 10 million euros
   - ○ 10–50 million euros
   - ○ 50–100 million euros
   - ○ 100–500 million euros
   - ○ More than 500 million euros
   - ○ Cannot say
4. Number of employees:
   - ○ Less than 50
   - ○ 50–100
   - ○ 100–500
   - ○ 500–1000
   - ○ 1000–2000
   - ○ More than 2000
   - ○ Cannot say

5. Country of company headquarters:

COUNTRY LIST

6. Nordic countries, where operate (multi-selections possible):
   - □ Denmark
   - □ Finland
   - □ Iceland
   - □ Norway
   - □ Sweden
   - □ Cannot say

7. What are the main roles of your company in the supply chain (multi-selections possible):
   - □ Raw material provider
   - □ Component provider
   - □ Technology provider
   - □ Equipment provider
   - □ End-product manufacturing
   - □ Service provider
   - □ Recycling service provider
   - □ Software provider
   - □ Automation & ICT provider
   - □ Other, please specify? ___________________________________
   - □ Cannot say

B. Tracking environmental and social impacts in the supply chain

8. What kind of actions has your company taken on environmental and social performance (multi-selections possible)?
   - □ Legal compliance statement
   - □ Incorporated environmental and social issues in company (policy, code of conduct, supplier policy, etc)
   - □ Keeping track of suppliers throughout the supply chain
   - □ Environmental Management System (e.g. ISO standards 14000) or other voluntary scheme like GRI Reporting
   - □ Assessment of environmental performance (of suppliers, in the supply chain and /or through LCA)
   - □ Company programs for improving environmental and ethical performance including design for Environment
   - □ Occupational health, safety protection programs and working conditions (e.g. EU-OSHA, ILO)
   - □ Other, please describe ___________________________________
   - □ Cannot say

9. Is your company aware of *the materials* used in your products?
   - o Yes
   - o No, but we are working on it
   - o Cannot say

10. Comments

OPEN ENDED

Metals are non-renewable resources and the use of metals is associated with several challenges. Metal extraction and processes cause, among others, impacts to physical landscapes, acidity of soils, contamination of water and degradation of groundwater quality, and increase air-borne dust and other emissions. Metal extraction has also been linked to fuelling armed conflicts such as in Congo. Many mine workers are risking their lives in bad work conditions and several abuses occur such as the use of child labour, violence towards workers and very poor wages.

Rare Earth Metals (REMs) are used extensively in cleantech applications due to their unique chemical, magnetic and electrical characteristics. Despite their name, REMs (e.g. lanthanum, cerium, praseodymium and neodymium) are not actually considered rare. However, the process for extracting these metals and isolating the ores in which they are found is highly technical, extremely difficult and environmentally hazardous. REMs come currently mainly from China adding geopolitical aspects to the social and environmental problems. In general, the recycling and recovery of Rare Earth Metals and other critical metals used in cleantech applications occurs at a low level and less than 1% is recycled from old scrap due to ineffective recycling collection and sorting systems.

11. How aware is your company of these problems related to metal use in the supply chain
    - o 5 = Very aware
    - o 4
    - o 3
    - o 2
    - o 1 = Not aware
    - o Cannot say
12. Which are the most critical metals for your product (name or chemical symbol)?

OPEN ENDED

13. Are you aware of *the origin* of the metals used in your products?
    - o Yes
    - o No, but we are working on it
    - o Cannot say
14. Does your company have a reporting tool/system for tracing the metals used in your products?
    - o Yes
    - o No, but we are evaluating/ developing a tool
    - o No
    - o Cannot say
15. Is your company taking actions to reduce environmental impacts of the metals used along your product's life cycle?
    - o Yes
    - o No
    - o Cannot say

16. If yes, please describe what kind of actions (multi-selections possible)?
    - □ Prefer environmentally and socially responsible suppliers and partners
    - □ Improve the traceability of the metals used
    - □ Look into using more recycled metals in our production
    - □ Replacing metals with materials with less environmental impacts
    - □ Improving energy efficiency in our production
    - □ Improving material efficiency in our production
    - □ Provide users more information on energy efficient use of our products
    - □ Improve the recyclability of our end-of-life products
    - □ Other means, please describe ________________________________
    - □ Cannot say
17. Comments

OPEN ENDED

C. Substitutes and replacements

18. Have you been searching substitutes or replacements for any metals used in your product?
    - o Yes
    - o No
    - o Cannot say
19. If yes, what was the reason for substitutions/replacements (multi-selections possible)?
    - □ Problems with the availability of the metal(s)
    - □ Insecurity about future availability and supply of the metal(s)
    - □ Cost of metal(s)
    - □ Environmental concerns related to the extraction of the metal(s)
    - □ Social problems related to the extraction of the metal(s)
    - □ More economic and/or less energy-intensive solutions
    - □ Stakeholder pressure linked to the use of the metal(s)
    - □ Other reason, please specify? ________________________________
    - □ Cannot say
20. Have/are you working with external R&D partners (e.g. companies, research institutes, industry associations etc.) on substitutes/replacements?
    - o Yes, please specify ________________________________
    - o No, we are working independently
    - o Cannot say
21. Comments

OPEN ENDED

D. Suppliers and cooperation

22. Do you have a procurement policy for suppliers addressing compliance with environmental and/or social laws, regulations or specific codes of conduct?
    - ○ Yes
    - ○ No
    - ○ Cannot say
23. If yes, please specify the specification of the procurement policy (multi-selection possible):
    - □ Legal compliance statement
    - □ Incorporated environmental and social issues in company (policy, code of conduct, supplier policy, etc)
    - □ Keeping track of suppliers throughout the supply chain
    - □ Environmental Management System (e.g. ISO standards 14000) or other voluntary scheme like GRI Reporting
    - □ Assessment of environmental performance (of suppliers, in the supply chain and /or through LCA)
    - □ Company programs for improving environmental and ethical performance including design for Environment
    - □ Occupational health, safety protection programs and working conditions (e.g. EU-OSHA, ILO)
    - □ Other, please describe ______________________________
    - □ Cannot say
24. Are you involved in any associations, initiatives etc. to improve traceability of minerals and ensure responsible sourcing, improve recyclability and/or sustainability of your products' supply chain?
    - ○ Yes
    - ○ No
    - ○ Cannot say
25. Please describe or comment:

OPEN ENDED

E. Needs and final comments

26. What kind of needs do you have to improve responsible supply management of the metals used in your products and improve recycling?

OPEN ENDED

27. Any other comments?

OPEN ENDED

Appendix 2:

Most commonly used metals in electric vehicles

Cerium (Ce) is used largely as a catalyst and is the most abundant rare earth metal in the earth's crust.[193] Cerium is used in NiMH batteries of electric vehicles. Cerium is found in a number of minerals, mainly allanite, bastnäsite and monazite. Bastnäsite deposits are largely in China and the United States. Monazite deposits are located in Australia, Brazil, China, India, Malaysia, South Africa, Sri Lanka, Thailand, and the United States.[194]

Cobalt (Co). Cobalt's major uses are in superalloys, catalysts, and batteries (including electric vehicles).[195] Over half of worldwide cobalt production is mined in Zambia and the Democratic Republic of Congo in the so-called Copperbelt region.[196] Cobalt mining and processing is linked to several social and environmental problems. The End-of-Life Recycling Rate of Cobalt is above 50% at present.[197]

Dysprosium (Dy). The main use of dysprosium is in neodymium-iron-boron magnets for applications such as hard disc drives, automobiles and motors, as well as in wind energy generation. The demand for dysprosium is likely to grow rapidly during the coming years due to competition over rare earth magnets. Demand could increase by 2,600% over the next 25 years (see figure 1). Dysprosium production is almost entirely concentrated in China. Further large reserves of rare earth elements can be found in the Commonwealth of Independent States and in the United States. In Europe, rare earth element reserves are known to be present in Norway. Dysprosium does not occur as a free element in nature but can be found in various minerals forming several brightly coloured salts. Together with Neodymium, they have exceptional magnetic properties that make them especially well-suited to use in highly efficient, lightweight motors and batteries. There is a potential to recycle neodymium and dysprosium from pre-consumer magnets, although further R&D of the recycling technologies is required. Efforts to replace neodymium and dysprosium in permanent magnet applications have so

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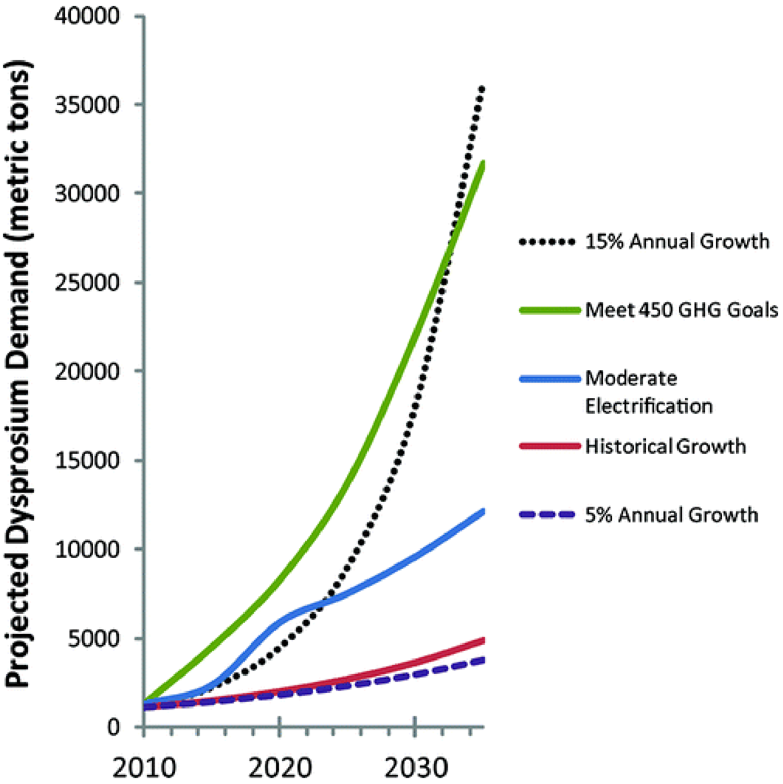
193 Moss et al (2011).
194 http://www.chemicool.com/elements/cerium.html#Abundance
195 Moss et al (2011).
196 Rajala (2008).
197 Moss et al (2011).

far not met much success and system level substitution, i.e. replacing the technologies that use rare earths with alternative technologies not reliant on permanent magnets, appears to be a more promising route. Continuing investment in alternative technologies is therefore important.[198]

Figure 1. Projected dysprosium demand (metric tons)[199]



Europium (Eu) and Yttrium (Y) are mainly used as a phosphor and also for example in LCD screens in electric vehicles. Both are rare earth elements. The largest reserves of Europium are in China, USA and Commonwealth of Independent States and leading producers are China, Russia and Brazil.[200] China is also the main producer of Yttrium.

Lanthanum (La) is usually employed as a battery constituent, especially in NiMH-based batteries. The largest reserves of lanthanum are in China, USA and Commonwealth of Independent States and largest pro-

[198] http://web.mit.edu/newsoffice/2012/rare-earth-alternative-energy-0409.html#.T4MjarahtXA.mailto, Moss et al (2011).
[199] Alonso et al (2012).
[200] http://www.rsc.org/periodic-table/element/63/Europium

ducers are China, Russia and Brazil.[201] There can be a possible shortage in lanthanum if growth in hybrids is strong and NiMH remains the preferred battery of choice.[202]

Lithium (Li). Lithium's major use in batteries. Largest reserves of lithium are in Bolivia, Chile and China. Main producers are Australia, China and Portugal. Lithium is found combined in small amounts of nearly all igneous rocks and in the waters of many mineral springs.[203] It has also been discovered in Finland.[204] Most EV/hybrid manufacturers are moving from NiMH batteries towards lithium-based batteries. This technology is not reliant on Rare Earths.[205]

Neodymium (Nd) is used, as in the case of dysprosium, in magnets in wind turbines and electric motors for hybrid cars. Neodymium (Nd) is the second most abundant rare earthmetal in the earth's crust after cerium. Currently, most neodymium is extracted in bastnäsite. China has a monopoly in neodymium production and has the largest reserves. Other small producers are India, Brazil and Malaysia. Further large reserves are in Commonwealth of Independent States and in the United States. In Europe, present best known reserves are in Norway. In Greenland, Finland and Sweden there are existing reserves, but they have been considered uneconomic for extraction.[206] The recycling potential and alternatives are the same as for dysprosium, which was discussed above.

Praseodymium (Pr) is mainly used in glass manufacture and magnets. It is used in small amounts in Neodymium-Iron-Boron (NdFeB) magnets.

Praseodymium can be used to improve the corrosive resistance of the magnet alloys. To some extent it can directly substitute for neodymium, without a severe impact on properties, if prices of the latter are unfavourable. [207] The main reserves and producers of praseodymium are the same as for many other rare earth metals. The largest reserves are in China, USA and Commonwealth of Independent States and largest producers are China, Russia and Brazil.[208]

Samarium (Sm) is used in magnets. Samarium cobalt magnets are the closest known magnetic materials to neodymium magnets in terms of performance. However, these magnets have around half the magnetic strength of neodymium-based magnets and are therefore far less suitable for use in EV motors.[209] Samarium is mined and produced in the

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[201] http://www.rsc.org/periodic-table/element/63/Europium
[202] Kara et al (2010).
[203] http://www.rsc.org/periodic-table/element/3/lithium
[204] http://yle.fi/alueet/hame/2011/04/akkuteollisuuden_himoamaa_litium-metallia_tammelan_kallioperassa_2535918.html
[205] Kara et al (2010).
[206] http://web.mit.edu/newsoffice/2012/rare-earth-alternative-energy-0409.html#.T4MjarahtXA.mailto
[207] Kara et al (2010).
[208] http://www.rsc.org/periodic-table/element/59/praseodymium
[209] Kara et al (2010).

same countries as mentioned above, such as in the case of praseodymium.[210] Samarium is not found free in nature, as in also the case of other rare earth elements. It is contained in many minerals, including monazite, bastnäsite, cerite, gadolinite and samarskite.

Terbium (Tb) is used in magnets. It is used in small amounts in Neodymium-Iron-Boron (NdFeB) magnets. Terbium can perform a similar function to dysprosium. However, its supply is even more limited. If supply was not a problem, terbium would probably be preferred, as it has a stronger influence on coercivity with a lesser impact on remanence (magnetization left after an external magnetic field is removed).[211] Terbium is also mined and produced in the same countries mentioned in the elements of praseodymium and samarium.

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[210] http://www.rsc.org/periodic-table/element/62/samarium
[211] Kara et al (2010).

Appendix 3:

Most commonly used metals in photovoltaics

Cadmium (Cd). The most common use of Cadmium is in NiCd batteries (85%) and in pigments (10%).[212] Cadmium telluride (CdTe) is used in solar thin films. The largest producers of Cadmium are Asian: China, Kazakhstan, Japan and South Korea. However, cadmium production is not very concentrated and these countries account for less than half of the refinery production in 2010. China and India hold around a third of all cadmium reserves worldwide. The demand of cadmium has exhibited a decline over the past years as it is being phased out in several applications such as pigments due to its health and environmental concerns. In addition, the use of cadmium in batteries, the major application for cadmium, is declining as alternative technologies such as NiMH and Li-Ion batteries are providing increasing competition. Cadmium is a by-product of zinc refining. Cadmium recycling, and therefore overall cadmium supply, is increasing due to environmental legislation. Possibly primary production of cadmium from zinc refining may decline due to lower commercial incentives.[213]

Copper (Cu) sees wide used in pure form in conducting electricity and heat. Copper is used in solar thin films. Major copper producers include Chile, United States of America, Canada, Russia, Indonesia, Australia, Peru, China, Zambia and Poland. It is also refined in other European countries to a lesser extent, including Nordic countries of Finland, Sweden and Norway.[214] The End-of-Life Recycling Rate of Copper is above 50% at present.[215]

Gallium (Ga). Gallium's principal use is in electronics: ICs, LEDs, diodes, solar cells[216]. Gallium is almost completely a by-product of alumina production. Demand growth for gallium is forecast to be around 10% per annum, which is mainly driven by fast growth in PV applications. The major producers of gallium are China, Germany, Ukraine, and Kazakhstan. A significant share of the world's total gallium output comes

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[212] UNEP (2011a).
[213] Moss et al (2011).
[214] Moss et al (2011).
[215] Moss et al (2011).
[216] UNEP (2011a).

also from secondary production, from the recycling of scrap such as in recycling plants in Canada, Germany, Japan, UK and USA.[217] This however applies mainly to the recycling of new scrap created in the manufacturing process. Recycling of old scarp is low due to the difficulty of collecting the products. Furthermore, the metal content in the products can be low and recycling technologies are often lacking.[218] Substitutes are available or are being developed for gallium in a number of applications. However the complete replacement of GaAs in all semiconductor applications looks unlikely at present.[219]

Germanium (Ge) is used mainly in night vision (infrared) lenses (30%), PET catalysts (30%), fiber optics, and solar cell concentrators.[220] Main producers of germanium are China, Russia and USA. Germanium can be used as a replacement for gallium and tellurium in electronic applications, but it is however also rather scarce.[221]

Indium (In). Indium's principal use is as a coating in flat-panel displays. It is also used in solar thin films.[222] Indium demand within solar PV is forecast to grow rapidly over the coming decade. Indium is most commonly recovered as a by-product of zinc-suphide, which is why exact figures of indium reserves are not available. Largest reserves are in China. Other much smaller reserves can be found in Peru, USA and Canada. The largest producers of indium are China, Republic of Korea and Japan. In addition to primary production, recycling of post-industrial waste is commn as approximately 70% of the indium contained in the main product indium tin oxide (ITO) can be recovered and refined for re-use. For PV, recycling of pre-consumer production waste of Copper indium gallium (di)selenide (CIGS) already occurs at Umicore in Belgium, which recovers metals from high-grade PV residues. These are typically production scrap residues from CIGS (thin-film solar cells), which are processed to recover the copper, indium, selenium and gallium. For post-consumer waste, recycling is almost non-existent, as indium and gallium concentrations in general PV waste are too low for economic recycling even with complete separation.[223]

Selenium (Se). Selenium is employed in glass manufacture, manganese production, LEDs, photovoltaics, and infrared optics. Selenium shares many charactaristics with sulphur and tellurium (below). Selenium is often found as a compound of other ores and is often a by-product

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[217] http://web.mit.edu/newsoffice/2012/rare-earth-alternative-energy-0409.html#.T4MjarahtXA.mailto, Moss et al (2011).
[218] UNEP (2011a).
[219] Moss et al (2011).
[220] UNEP (2011a).
[221] Moss et al (2011).
[222] Moss et al (2011).
[223] Moss et al (2011).

of copper production. Largest producers include Japan, Germany, Belgium, Canada and Russia. Finland has also significant refinery production. Large reserves are in Chile, Russia, USA and Peru. Demand of selenium is expected to be moderate.[224] For recycling of selenium from thin-film solar cells, see above on indium.

Silver (Ag). Silver's principal uses are in electronics, industrial applications (catalysts, batteries, glass/mirrors) and jewelry.[225] Silver has the highest electrical and thermal conductivity of all metals and is a by-product copper and led-zinc ores. Leading producers of silver are Peru, Mexico and China where copper and led-zinc ores are mined in vast quantities. Largest reserves can be found in Peru, Chile, Australia and Poland. Relatively large reserves have also been found in Sweden. Currently, approximately 20% of the world's silver supply comes from recovering silver from scrap. However, recycling rates vary in different usage sectors.[226]

Tellurium (Te) Tellurium's uses include steel additives, solar cells, and thermoelectrics. Demand in tellurium is expected to increase rapidly over the next ten years due to PV applications. Tellurium is rarely found in its pure state but as a compound in ores of bismuth, copper, gold, lead, mercury, nickel, silver and zinc. Almost all tellurium currently produced is obtained as a by-product of copper refining. Known producers include Japan, Russia, Canada and Peru. Siginifant European producers include Belgium, Germany and Finland. Figures for tellurium secondary production are also unknown, although small quantities of new scrap from CdTe production are known to be recycled, also from PVs.[227]

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[224] Moss et al (2011).

[225] http://web.mit.edu/newsoffice/2012/rare-earth-alternative-energy-0409.html#.T4MjarahtXA.mailto, Moss et al (2011).

[226] Moss et al (2011).

[227] Moss et al (2011).

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Tracking environmental impacts in global product chains

Tracking environmental impacts in global product chains – Rare Earth Metals and other critical metals used in the cleantech industry

Metals form a central part of the global economy, but their extraction and supply are linked to several environmental and social concerns. This study aims to create a picture of the supply chain of Rare Earth Metals (REMs) and other critical metals used in the clean technology (cleantech) sectors of electric vehicles and solar panels.

The study examines how Nordic cleantech companies are aware and acting on the challenges related to the lifecycle of these metals and what are the potentials to minimise environmental and social impacts. Recommendations of the study can be summarised as three initiatives: establishment of an awareness platform and roundtable initiative (short-term), research and information gathering (mid-term), and development of closed-loop solutions (long-term).

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