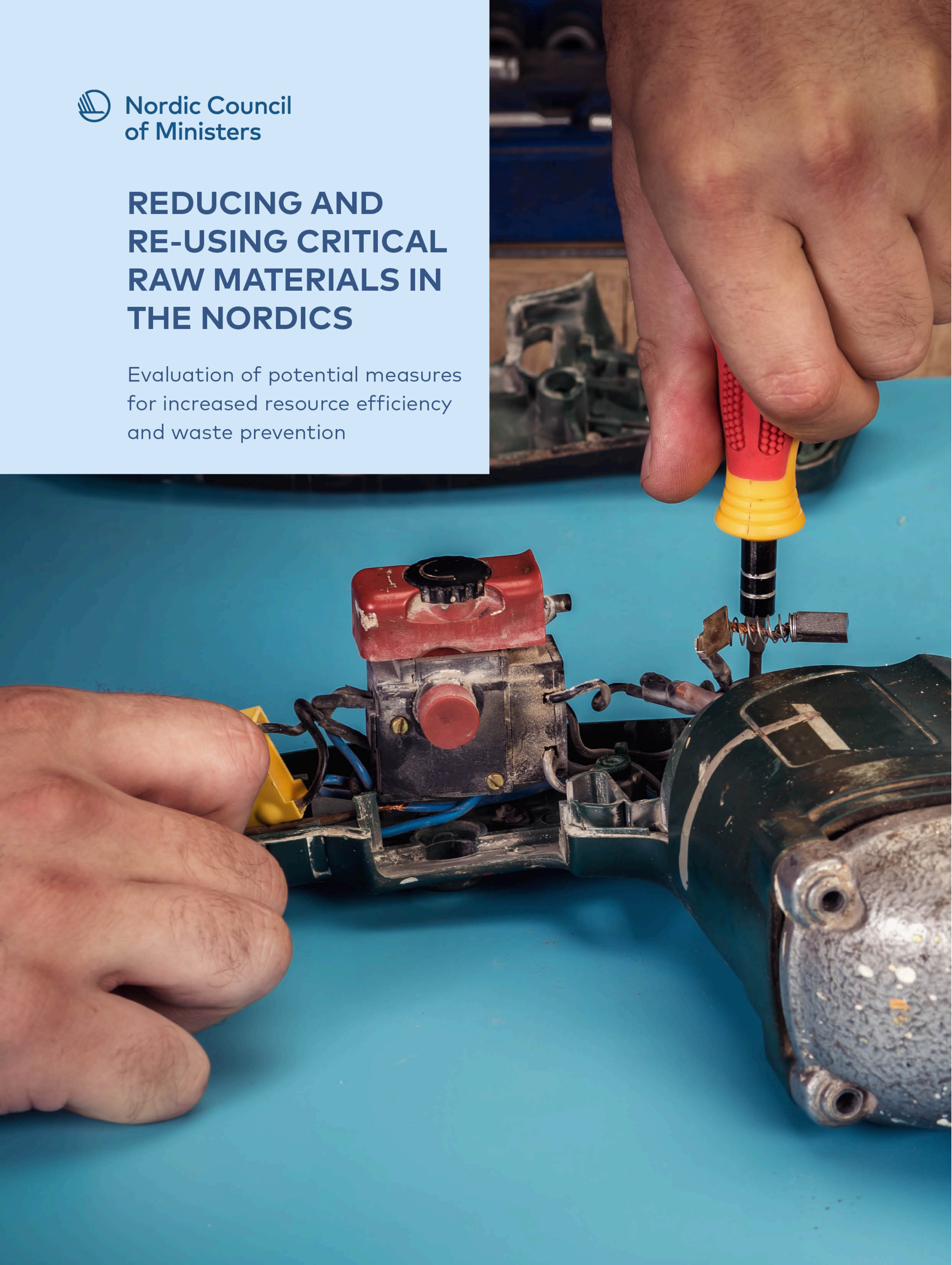
Nordic Council of Ministers

REDUCING AND RE-USING CRITICAL RAW MATERIALS IN THE NORDICS

Evaluation of potential measures for increased resource efficiency and waste prevention



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Summary

This report is the third and final part in a series addressing resource efficiency concerning critical raw materials (CRM) in the Nordic region. CRMs are defined by the European Union (EU) as materials of high economic importance with significant supply risk. To ensure a secure and sustainable supply of critical raw materials, the EU has launched the Critical Raw Materials Act (CRMA). The act contains regulations aimed at, but not limited to, improving EU extraction, processing, and recycling capacities. The Act also emphasises waste prevention and initiatives to increase the re-use of discarded products and materials as a part of a broader strategy to secure CRM supply chains.

Article 26 of the CRMA requires member states to develop and implement national programmes containing measures designed to *"promote waste prevention and increase re-use and repair of products and components with relevant critical raw materials recovery potential"*. This report outlines potential measures and instruments for consideration in designing these programmes.

In May 2024, the CRMA entered into force, which means that the regulation already binds Denmark, Finland and Sweden, while Iceland and Norway are currently assessing its EEA relevance.

Almost all products and materials consumed by humans impose a negative environmental footprint throughout their lifecycle. The extraction and processing of raw materials require energy and chemicals, generating waste, pollution and significant disruption to landscapes and ecosystems. Recycling mitigates the need to extract virgin raw materials and often reduces energy consumption and waste generation. However, while the overall environmental footprint of secondary materials is typically much smaller than that of their primary equivalents, it remains substantial. The only products or materials with no negative environmental footprints are those that are never produced or consumed.

Waste prevention measures aim to reduce the total amount of waste generated or minimising specific chemical components within waste, such as hazardous substances or critical raw materials. While recycling primarily focuses on measures after a product or material has been discarded, waste prevention emphasises actions taken earlier in the product lifecycle. Effective measures for CRM waste prevention should prioritise products and materials that contain significant quantities of CRMs. Such products include electronics, vehicles and renewable energy production and distribution systems.

Circular product design aims to minimise CRM content in the products, reduce CRM material losses during the manufacturing process, and extend product longevity through robust designs that facilitate maintenance, repairs and upgrades to maintain functionality and combability. Certain CRM-intensive products, such as mobile phones, laptops, tablets and screens, are particularly suited for life extension due to their frequent usage. Additionally, many CRM-intensive electronic components, including motors, batteries, and cables, can benefit from extended lifespan through proper maintenance, repairs, and upgrades. Key measures to facilitate this include access to repair parts, detailed repair instructions, and secure systems for data deletion to build user confidence during ownership transfers. Furthermore, product designs should enable discarded products and materials to be easily refurbished or remanufactured for continued use. For instance, aluminium panels from demolished buildings or infrastructure can be refurbished and repurposed in new construction projects.

CRM waste can also be reduced or eliminated through **adjustments to production processes**. One approach involves improving processes that allow the production of the same products and materials with reduced or eliminated inputs of CRMs. An example of such innovations is the direct reduction of steel, where the use of the CRM coke is replaced by hydrogen and electricity. Another example is the production of primary aluminium using inert anodes and chlorine salts, which can reduce or eliminate the need for CRMs such as fluorspar and graphite in the process. Waste prevention can also be achieved through miniaturising products or components, thereby minimising the total CRM consumption per product. For instance, printed circuit boards are now typically smaller and contain lower amounts of many CRMs compared to older, similar circuit boards.

The **use phase of a product or material** is a crucial stage for waste prevention. By avoiding the consumption of non-essential products and materials or by extending the use phase for consumed products and materials through considerate and practical use that includes maintenance, reparations and upgrades necessary to maintain full functionality for as long as possible, significant waste reduction can be achieved. Strategies for waste prevention during the use phase are often summarised using the keywords refuse, reduce, re-use, repair, refurbish and rethink.

Consumption habits can play a significant role in reducing CRM waste. Individuals can make a substantial impact by reducing their total consumption of CRM-containing materials. Possible measures that facilitate this include information campaigns that raise consumer awareness regarding CRM concerns and lead to voluntary consumption restrictions. Economic measures like adding a fee to certain products and materials that make their consumption more expensive can also influence consumer behaviour. Legal instruments like banning or restricting specific CRM-intensive products and materials for particular non-essential use can reduce CRM waste but may be seen as controversial. Product applications considered non-essential include entertainment purposes like party balloons and fireworks. The CRM use of helium gas can easily be significantly reduced by banning the use of helium in party balloons. Similarly, some consumption of several CRMs, including strontium, magnesium and barium, can be reduced by prohibiting or restricting the use of fireworks. This may however encourage illegal import and distribution of the banned products.

Re-use refers to the process where still functional products and materials that would otherwise be discarded as waste are taken over and used by new consumers. Cars, bicycles, furniture, EEE-products and textiles are examples of products that are commonly re-used by new consumers through transactions on second-hand markets. There is also a developing market for re-used construction materials. Discarded products and materials can also be re-used after being collected as waste. This will however often require additional preparation before being ready for a new user life compared to exchanging the products between users before being discarded as waste.

Waste prevention is used as a concept covering strategies for both reducing the total amounts of waste and minimising the concentration of specific chemical components of the waste like hazardous substances or critical raw materials. If a material or chemical component is to be replaced without loss of functionality it must be replaced by an alternative substance that provides similar properties while being less hazardous or scarce. This operation is often referred to as substitution. However, finding alternative materials with acceptable properties are often challenging, and can therefore in the worst-case lead to substitutions that have undesirable product effects like loss of functionality, or increased health hazards.

The following measures are discussed in this report:

Measures for waste prevention

- Reduced use of helium for entertainment purposes
- Reduced use of aluminium for packaging purposes
- Eliminate the use of coke in steel production
- Adopt alternative technology for the primary production of aluminium that eliminates the need for fluorine and anode graphite
- Reduced use of copper for chemicals
- Reduced use of rare earth elements (REE) for pigment, ceramic products and glass production
- Reduced use of CRMs for fireworks
- Reduced use of critical raw materials in small electronics in consumer products
- Increase the number of CRMs and overall extraction efficiency from ore mined in the Nordic region.

Instruments and measures for re-use

- Assess the possibility of reusing optical cables with CRM content
- Reusing magnets in electric motors, pumps and "dynamos"
- Reusing CRM components in discarded EE products
- Increasing the number of insurance settlement cases where used products or assisted repair services are provided as compensation instead of new products.

Sammendrag

Dette er den siste rapporten i en serie av totalt tre rapporter som vurderer mulighetene for å forbedre nordisk ressurseffektivitet for kritiske råmaterialer (CRM). CRM er definert av EU som materialer av høy økonomisk betydning og som samtidig er forbundet med betydelig forsyningsrisiko. Ut fra et ønske om å redusere slik risiko har EU innført *Critical Raw Materials Act* (CRMA) som inneholder bestemmelser som skal styrke europeisk egenkapasitet for utvinning, raffinering og gjenvinning av CRM. Loven vektlegger også avfallsforebygging og peker på tiltak for å øke gjenbruk av kasserte produkter og materialer som en del av en bredere strategi for å styrke egen CRM-forsyning

Artikkel 26 i CRMA krever at medlemslandene setter opp og implementerer nasjonale programmer som inneholder tiltak utformet for å *«fremme avfallsforebygging og øke gjenbruk og reparasjon av produkter og komponenter med relevant kritisk råstoffgjenvinningspotensial».* Denne rapporten skisserer mulige tiltak og virkemidler som kan inngå i disse programmene.

CRMA trådte i kraft i mai 2024 og dette innebærer at loven allerede er bindende for Danmark, Finland og Sverige, mens Island og Norge for tiden vurderer hvorvidt CRMA er EØS-relevant.

Nesten alle produkter og materialer som konsumeres av mennesker er forbundet med et negativt miljøavtrykk gjennom sin livssyklus. Utvinning og prosessering av råvarer krever energi og kjemikalier, og skaper avfall, forurensning og betydelig forstyrrelse av landskap og økosystemer. Resirkulering reduserer behovet for å utvinne jomfruelige råvarer og reduserer ofte tilhørende energiforbruk og avfallsproduksjon. Selv om det samlede miljøavtrykket til sekundære materialer vanligvis er mye mindre enn hva som oppstår ved fremstilling av tilsvarende mengder primære materialer av samme type, er det imidlertid fortsatt betydelig. De eneste produktene eller materialene helt uten negative miljøfotavtrykk er derfor kun de som aldri blir produsert eller konsumert.

Avfallsforebyggende tiltak tar sikte på å redusere den totale mengden avfall som oppstår eller minimere spesifikke kjemiske komponenter i avfallet, som for eksempel farlige stoffer eller kritiske råvarer. Mens resirkulering først og fremst fokuserer på tiltak etter at et produkt eller materiale har blitt kassert, legger avfallsforebygging større vekt på tiltak som trer i kraft tidligere i produktets livssyklus. Skal tiltak for forebygging av CRM-avfall være effektive bør tiltakene sikte seg inn på produkter og materialer som inneholder betydelige mengder CRM. Slike produkter inkluderer elektriske og elektroniske produkter, kjøretøy samt produksjons- og distribusjonssystemer for fornybar energi.

Sirkulær produktdesign tar sikte på å minimere CRM-innhold i produktene, samt redusere tap av CRM-materialer under produksjonsprosessen. Designfasen søker også å forlenge produktenes levetid gjennom robust design som legger til rette for effektivt vedlikehold, reparasjoner og oppgraderinger som muliggjør opprettholdelse av funksjonalitet og kompatibilitet over lang tid. Enkelte CRM-intensive produkter, som mobiltelefoner, bærbare datamaskiner, nettbrett og skjermer, er spesielt egnet for levetidsforlengelse på grunn av store bruksvolumer og hyppig utskiftning. I tillegg kan også mange CRM-intensive elektroniske komponenter, inkludert motorer, batterier og kabler få forlenget sin levetid gjennom riktig vedlikehold, reparasjoner og oppgraderinger. Viktige tiltak for en slik utvikling inkluderer tilgang til reservedeler, detaljerte reparasjonsinstruksjoner og sikre systemer for sletting av data i forbindelse med at produkter overtas av en ny bruker. Videre bør produktdesign gjøre det enkelt å pusse opp eller oppgradere kasserte produkter og materialer for fornyet bruk. For eksempel kan aluminiumsplater fra rivning av gamle bygninger eller infrastruktur pusses opp og brukes på nytt i nye byggeprosjekter.

CRM-avfall kan også reduseres gjennom **justering av produksjonsprosessene**. En tilnærming kan være prosessendringer som tillater produksjon av de samme produktene og materialene med redusert tilførsel av CRM. Et eksempel på slike innovasjoner er direkte reduksjon av stål, hvor bruk av koks (som er definert som CRM av EU) erstattes av hydrogen og elektrisitet. Et annet eksempel er produksjon av primæraluminium ved bruk av inerte anoder og klorsalter, som kan redusere eller eliminere behovet for CRM-er som fluor og grafitt i prosessen. Avfallsforebygging kan også oppnås gjennom å miniatyrisere produkter eller komponenter, og dermed minimere det totale CRM-forbruket per produkt. For eksempel er dagens elektroniske kretskort vanligvis mindre enn sine eldre forgjengere, og inneholder ofte mindre mengder av mange CRM-er per kort.

Bruksfasen til et produkt eller materiale gir også mange muligheter for avfallsforebygging. Ved å unngå eller begrense eget forbruk av ikke-essensielle produkter og materialer vil tilhørende CRM-konsum også minimeres. Gjennom hensynsfull bruk og best mulig vedlikehold, samt reparasjoner og oppgraderinger som er nødvendige for å opprettholde full funksjonalitet så lenge som mulig, kan også mye avfall minimeres. Sentrale strategier for avfallsforebygging i bruksfasen oppsummeres ofte ved hjelp av de engelske stikkordene refuse, reduce, re-use, repair, refurbish og rethink.

Justering av egne **forbruksvaner** er således et viktig tiltak for å minimere CRM-avfall. Enkeltpersoner kan begrense sitt CRM-konsum i betydelig grad gjennom sine forbrukervalg. Mulige tiltak som legger til rette for endret forbrukeradferd inkluderer informasjonskampanjer som øker forbrukernes bevissthet om CRM-hensyn og dermed fører til frivillige forbruksrestriksjoner.

Økonomiske tiltak som for eksempel avgift på CRM-holdige produkter og materialer som gjør forbruket dyrere kan også påvirke forbrukeratferd i retning av mindre avfall. Juridiske virkemidler som forbud eller andre typer restriksjoner på bruk av spesifikke CRM-intensive produkter og materialer for spesiell ikke-essensiell bruk kan også redusere CRM-avfall i betydelig grad, men vil ofte være kontroversielt. Ikke-essensielle CRM-applikasjoner inkluderer underholdningsformål som festballonger og fyrverkeri. CRM-bruken av heliumgass kan enkelt reduseres betydelig ved å forby bruk av helium i festballonger. På samme måte kan noe av forbruket av CRM-er som strontium, magnesium og barium, reduseres ved å forby eller begrense bruken av fyrverkeri. Dette kan imidlertid stimulere til ulovlig import og distribusjon av de forbudte produktene.

Ombruk refererer til prosessen der fungerende produkter og materialer som ellers ville blitt kassert som avfall, overtas og benyttes av nye brukere. Biler, sykler, møbler, EE-produkter og tekstiler er eksempler på produkter som ofte overtas av nye brukere gjennom transaksjoner på bruktmarkeder. Det er også et marked i utvikling for gjenbrukte byggematerialer. Kasserte produkter og materialer kan også gjenbrukes etter å ha blitt samlet inn som avfall. Dette vil imidlertid ofte kreve ytterligere forberedelser før de er klare for et ny bruk sammenlignet med om produktene overtas av nye brukere før de kastes som avfall.

Avfallsforebygging brukes som et konsept som dekker strategier for både å redusere de totale avfallsmengdene og minimere konsentrasjonen av spesifikke kjemiske komponenter i avfallet som farlige stoffer eller kritiske råmaterialer. Hvis et materiale eller en kjemisk komponent skal erstattes uten tap av funksjonalitet, må den erstattes av et alternativt stoff eller materiale med tilsvarende egenskaper samtidig som det er mindre farlig eller mer tilgjengelig. Dette omtales som substitusjon, og representerer en strategi for kvalitativ avfallsforebygging som gjør at farlige eller ressursbegrensede stoffer kan erstattes med andre mindre problematiske alternativer. Men å finne alternative materialer med akseptable egenskaper er ofte utfordrende, og kan derfor i verste fall føre til substitusjoner som har uønskede produkteffekter som tap av funksjonalitet eller gir økt helsefare.

Følgende tiltak er omtalt i denne rapporten:

Tiltak for avfallsforebygging

- Redusert bruk av helium til underholdningsformål
- Redusert bruk av aluminium til emballasjeformål
- Eliminere bruken av koks i stålproduksjon
- Ta i bruk alternativ teknologi for primærproduksjon av aluminium som eliminerer behovet for fluor og anodegrafitt
- Redusert bruk av kobber til kjemikalier
- Redusert bruk av REE til pigment-, keramikk- og glassproduksjon
- Redusert bruk av CRM for fyrverkeri
- Redusert bruk av CRM i småelektronikk i forbrukerprodukter
- Øke antall CRM-er og total utvinningseffektivitet for malm som oppredes i Norden.

Virkemidler og tiltak for gjenbruk

- Vurdere muligheten for gjenbruk av optiske kabler med CRM-innhold
- Gjenbruk av magneter i elektriske motorer, pumper og «dynamoer»
- Gjenbruk av CRM-komponenter i kasserte EE-produkter
- Økt bruk av brukte produkter og reparasjonstjenester som oppgjør i forsikringssaker

1. Introduction

This report is the third and final part in a series addressing resource efficiency concerning critical raw materials (CRMs) in Nordics.[1] Whereas the first two reports focused on CRM recycling, this report discusses how improved CRM resource efficiency can be achieved through other strategies within the waste hierarchy. The primary focus is on strategies for waste prevention and re-use of CRM-rich products and materials.

Article 26 of the Critical Raw Materials Act (CRMA) requires member states to adopt and implement a national programme containing measures designed to *"promote waste prevention and increase re-use and repair of products and components with relevant critical raw materials recovery potential"*. This report outlines potential measures and instruments to be considered when designing these programmes. From a list of 90 measures (Appendix 1), a selection of these measures is given a more in-depth evaluation in chapter 3. The first chapter of the report contains a more general discussion on how waste prevention concepts and principles defined by the Waste Framework Directive of EU can be best applied for increased CRM-resource efficiency.

1.1 Critical raw materials

Central aspects of critical raw materials are discussed more thoroughly in the first two reports of this series, hence, only a short description is provided here. Raw materials are defined by the EU as substances in processed or unprocessed state used as input for the manufacturing of intermediate or final products. Substances predominantly used as food, feed or combustion fuel are, however, excluded from this definition and not considered raw materials.[2]

Critical raw materials (CRM) are defined by the EU as materials of high economic importance with significant supply risks. To address these risks, the EU has introduced the Critical Raw Materials Act (CRMA), which establishes regulatory measures to enhance European capacity for extraction and refining. The Act also emphasises waste prevention and initiatives to increase the re-use of discarded products and materials as a part of a broader strategy to secure CRM supply chains.

In May 2024, the Critical Raw Material Act entered into force, which means that the regulations already bind Denmark, Finland, and Sweden, while Norway and Iceland are currently assessing their EEA relevance.

1.2 Waste prevention, re-use and substitution

Almost all products and materials consumed by humans impose a negative environmental footprint throughout their lifecycle. The extraction and processing of raw materials require energy and chemicals, generating waste, pollution and significant disruption to landscapes and ecosystems. Recycling mitigates the need for virgin raw materials and often reduces energy consumption and waste generation. However, while the overall environmental footprint from

1. https://pub.norden.org/temanord2024-513/
2. EU Critical Raw Material Act

secondary materials is typically much smaller than that of their primary equivalents, it remains substantial. The only materials or products with no negative environmental footprints are those that are never produced, as illustrated in Figure 1.1.

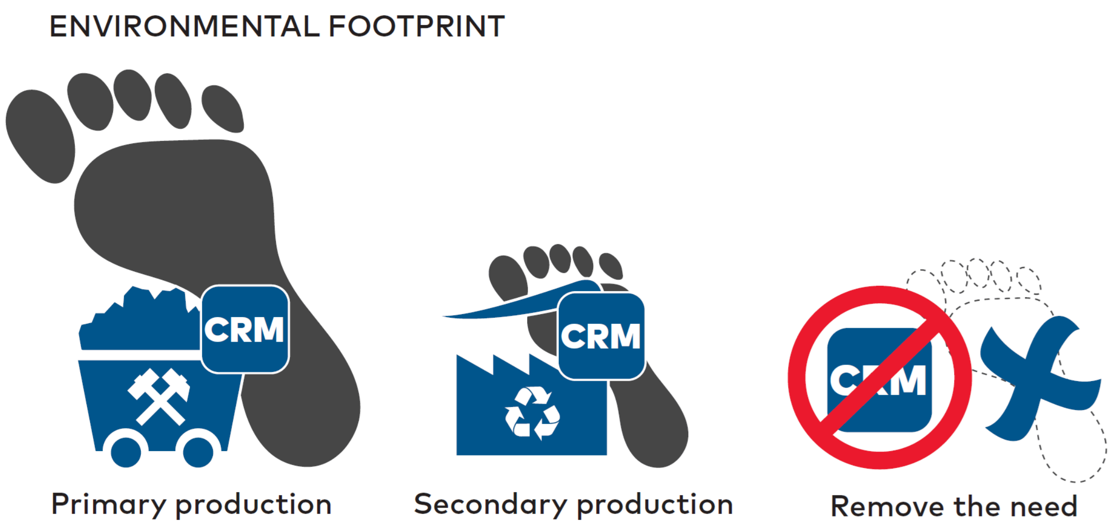

Figure 1.1 No products have a better environmental footprint than those we can do without. Illustration Bergfald Miljørådgivere.

Waste prevention refers to strategies aimed at eliminating or minimising the consumption of products and materials that would otherwise become waste. These measures can either reduce the overall amount of waste generated or minimise the presence of hazardous substances, certain chemical components, or critical raw materials. While recycling mainly addresses waste once discarded, waste prevention focuses on actions earlier in the product lifecycle.[3] Some measures focus on designing products and materials to minimise raw material consumption during production and extend their use phase. Other strategies focus on adjusting the manufacturing processes to utilise raw materials more efficiently. However, there are often trade-offs in achieving effective circular designs that reduce waste without creating unwanted inconveniences. For instance, minimising metal use in constructing an engine may result in a weaker design with a shorter product lifespan. Similarly, replacing a scarce or hazardous material with an alternative, such as copper for aluminium in electrical applications, could result in a loss of functionality or reduced energy efficiency.

The use phase of a product or material gives the consumer several opportunities to reduce waste. This includes avoiding the consumption of non-essential products and materials or extending the use phase for consumed products and materials through considerate and practical use that includes maintenance, reparations, and upgrades necessary to maintain full functionality for as long as possible. Strategies for waste prevention during the use phase are often summarised using the keywords refuse, reduce, re-use, repair, refurbish and rethink.

Re-use refers to the process where functioning products and materials that would otherwise be discarded as waste are instead repurposed and applied by new consumers in the same way. Cars, bicycles, furniture, EE products, and textiles are examples of products commonly reused through

3. Industrial symbiosis describes networks of industrial processes where residual materials generated in one process is utilized as a feedstock in another. As such industrial symbiosis may be considered both waste prevention and a form of recycling.

transactions on second-hand markets. Additionally, there is also a developing market for re-used construction materials. Discarded products and materials can sometimes also be prepared for re-use after being collected as waste.

Some business models can promote waste prevention through prolonged product lives and more efficient use of the products being distributed. One example is Product-Service-Systems (PSS) where products are rented out instead of sold. Retaining ownership to the product allows the business to plan maintenance and upgrades that can promote durability with full functionality over extended time periods compared to business models where the product is owned by the user. If done right, PSS may contribute to a change in consumer behaviour and reduce both consumption and waste. Business to business models may be of particular interest, where companies rent necessary office equipment instead of buying. This requires a design rethink while it may create business and job opportunities within a range of products. Nordic Council of Ministers have explored PSS models based on different products,[4] and while the results and the environmental impacts are varying, its implementation is sure to have socioeconomic effects and should be explored further, in particular related to products with a high content of CRM. PSS best potential for reducing CRM-waste so far seems to be for products that are only used a limited number of times, like handheld tools, party and event equipment or sports, camping and hiking gear. PSS may also enable replacement of single use aluminium in packaging and food services with reusable alternatives.

Waste prevention is used as a concept covering strategies aimed at both reducing the total volume of waste and minimising the concentration of specific chemical components within that waste, such as hazardous substances or critical raw materials. Chemical components of a product often contribute properties necessary for product functionality. In order to replace such components without compromising functionality, it is crucial to identify an alternative substance that can provide similar properties while being less hazardous or scarce. This process, known as substitution, represents a qualitative waste prevention strategy, enabling the replacement of hazardous or resource-limited substances with more benign or available alternatives. Substitution based on weak or flawed assessments may lead to unsuccessful substitutions resulting in products with unacceptable safety or functional performance. All substitution assessments should include an environmental evaluation that ensures that the chosen substitution material does not lead to products having more adverse environmental effects compared to the material being replaced.

Figure 1.2 summarises the sub-strategies included in the waste prevention concept.

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4. https://www.norden.org/no/node/90666

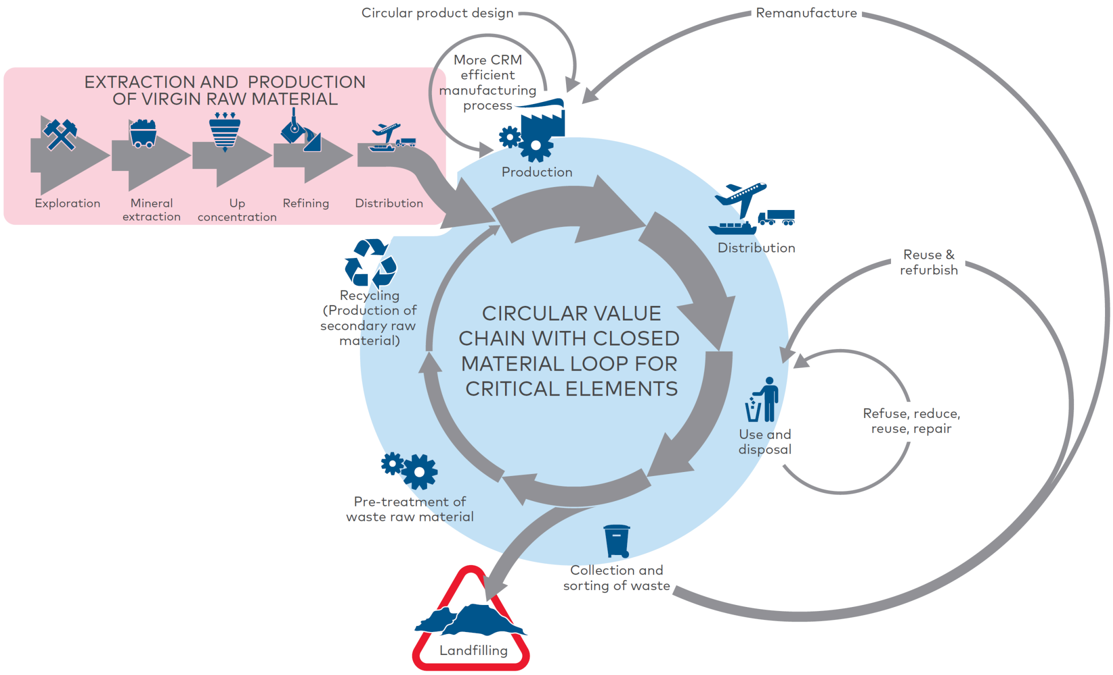

Figure 1.2 Strategies under waste prevention. Illustration Bergfald Miljørådgivere.

1.2.1 Political instruments for increasing waste prevention

CRM-waste prevention can be stimulated using both communications, economic- and legal instruments. Communication can be used to increase waste prevention through information campaigns that raise public awareness of increasing CRM-supply risks caused by consumption of certain products. Taxes or fees can be put on certain CRM-intensive products to limit consumption, or legal instruments can be used to ban these applications completely.

Critical raw materials have different applications ranging from life essential to purely entertainment based. The CRM helium is for instance used both in party balloons and in MRI-machines used for medical examinations. In a supply situation with limited availability of a CRM, restrictions on use of this CRM for non-essential applications may secure necessary supply for more essential uses. Ideally such restrictions would best be applied before the supply situation becomes acute.

Although legal restrictions in the form of a banning certain CRM-applications is the most efficient way to ensure CRM-waste prevention, this instrument is both controversial and comes with associated costs and risks. Banning certain applications limits both consumer and commercial freedoms and may lead to economic losses for producers and distributors of these applications. Banning an application may also encourage smuggling and illegal distribution of banned products which can also lead to poorer compliance with safety regulations as seen with illegally imported fireworks. Enforcing a ban also comes with added costs and encumbrances. Banning certain products is however not an uncommon practice in the Nordic countries or EU as a long list of banned products already exists due to unwanted content of hazardous substances. If certain products where to be banned due to CRM-supply concerns this can therefore be seen as an extension of an already well-established legal practice that is a part of the regulation of chemicals and hazardous substances. Examples of already banned products include mercury batteries, fire foam containing PFOS and phosphate-containing detergents.

1.3 Waste reduction as an EU strategy for better CRM-resource efficiency

To mitigate future supply risks for CRMs, the EU introduced the Critical Raw Materials Act, which provides regulations to strengthen European capacity for extraction and refining. Article 26 of CRMA requires member states to

«promote waste prevention and increase re-use and repair of products and components with relevant critical raw materials recovery potential;"

The member states shall develop and implement national programmes that include measures to improve CRM waste prevention. These can be outlined as either separate policy documents or as an integrated part of other national waste policy frameworks. Figure 1.3 illustrates potential methods for integrating waste management programmes, waste prevention initiatives or CRM resource efficiency programmes into a common policy plan.

Figure 1.3 Possible integrations of waste management programs, waste prevention programs and CRM-resource efficiency programs. Illustration Bergfald Miljørådgivere.

1.3.1 Other EU regulations that impact CRM waste reduction policies

In addition to CRMA, several other EU regulations affect the framework conditions for CRM-waste reduction. The following paragraphs summarise the most relevant regulations that include:

- Waste Framework Directive
- WEEE Directive
- Battery Directive
- End of Life Vehicle Regulation
- Eco Design Directive

Waste Framework Directive

The European Waste Framework Directive defines alternative waste treatment solutions and requires a national waste policy where these treatments are given priority according to the waste hierarchy. The directive lists the following methods as part of the hierarchy:

a. prevention
b. preparing for re-use
c. recycling
d. other recovery, e.g. energy recovery
e. disposal

The directive requires member states and those bound by the EEA agreement to take measures that encourage options delivering the best overall environmental outcomes.

The directive requires member states and those bound by the EEA agreement to develop national waste management plans. These plans must include measures to improve environmentally sound practices preparing for reuse, recycling, recovery, and waste disposal. Many of these measures align with the national programme for CRM recycling and other strategies aimed at reducing risks to CRM supply chains.

Article 3 of the EU Waste Framework Directive defines waste prevention as "measures taken before a substance, material or product has become waste, that reduces either the quantity of waste, adverse impacts of the generated waste or the content of hazardous substances in materials and products." Thus, the definition includes both quantitative aspects (reduced amounts of waste) and qualitative aspects (reduced amounts of certain chemical compounds in the waste and unwanted effects from the waste in the surroundings). The definition specifies that reuse and measures extending the life span of products shall be considered integrated parts of a waste prevention strategy

Article 9 of the Waste Directive lists the following measures as potential parts of a waste prevention strategy:

a. promote and support sustainable production and consumption models;
b. encourage the design, manufacturing and use of products that are resource-efficient, durable, reparable, re-usable and upgradable;
c. target products containing critical raw materials to prevent those materials from becoming waste;
d. encourage the reuse of products and the setting up of systems promoting repair and re-use activities, including in particular for electrical and electronic equipment, textiles and furniture, as well as packaging and construction materials and products;
e. encourage the availability of spare parts, instruction manuals, technical information, or other instruments, equipment or software enabling the repair and re-use of products;
f. reduce waste generation from industrial production, extraction of minerals, manufacturing, construction and demolition;
g. reduce the generation of food waste in primary production, in processing and manufacturing, in retail and other distribution of food, in restaurants and food services, as well as in households
h. encourage food donation and other redistribution for human consumption
i. promote the reduction of the content of hazardous substances in materials and products,
j. reduce the generation of waste, in particular, waste that is not suitable for preparing for re-use or recycling;
k. identify products that are the primary sources of littering, and take appropriate measures to prevent and reduce litter from such products;
l. aim to halt the generation of marine litter
m. develop and support information campaigns to raise awareness about waste prevention and littering.

As can be read from the list, EU-defined strategies for waste prevention include the circular design of durable products that facilitate repairability, thereby extending their lifespan. Additionally, resource-efficient manufacturing processes that minimise production waste are highlighted. The list also includes strategies for reusing and modifying consumer behaviour, such as raising awareness of sustainable consumption practices and forming a culture encouraging these habits. Waste prevention of CRM-containing products is listed as a special concern.

Annex IV of the Waste Framework Directive outlines additional measures for waste prevention. These include information campaigns to promote the best available techniques for waste prevention and educating competent authorities in incorporating waste prevention requirements into industrial permits. Furthermore, voluntary agreements should be used to set waste prevention plans and objectives for industries, as well as economic measures that provide incentives for waste prevention.

Article 29 of the Waste Framework Directive mandates that member states establish a national waste prevention programme outlining the implementation of measures specified in Article 9 and Annex IV. This programme may be structured as a separate plan or integrated into the national waste management plan or another relevant national environmental policy programme.

WEEE Directive

The first version of the WEEE Directive entered into force in 2003 and has since been updated several times. The EU is currently evaluating the need for further revisions.[5]

The directive describes required measures to reduce the adverse impacts of the generation and management of waste from electrical and electronic equipment (WEEE). The directive contains regulations regarding product design, waste collection and collection rates, treatment facilities and recovery rates. The current version of the directive includes overall benchmarks for recovery and preparation for re-use and recycling but not recycling benchmarks for specific CRMs like the Battery regulation and ELV regulation.

The Battery regulation

On 17 August 2023, the new Battery Regulation of the EU entered into force and replaces the Battery Directive from 2006.[6] The new regulation provides updated provisions on sustainability, safety, labelling, marking, and information to facilitate the market placement and service of batteries within the Union. Additionally, it outlines minimum requirements for extended producer responsibility, as well as the collection and treatment of end-of-life batteries. It includes reporting obligations that are an important part of the total framework under which Nordic CRM recycling for batteries will operate.

The regulation applies to all categories of batteries, including portable batteries, starting, lighting and ignition batteries (SLI batteries), light means of transport batteries (LMT batteries), electric vehicle batteries and industrial batteries. The regulation also applies to batteries incorporated into or added to products or specifically designed to be incorporated into or added to products.

Article 11 of the regulations introduces requirements for the removability and replaceability of portable and LMT batteries. These requirements will also benefit CRM-recycling operations as they may allow easier and more cost-effective dismantling of the battery components from the product and can prohibit the use of welding and glued connections that make disassembly difficult and time-consuming.

The Battery regulation also requires all batteries above a minimum size to be associated with a battery passport that is interoperable with other digital product passports required by the Eco design directive. The passport and battery labelling shall include information about CRMs present in the battery.

End-of-Life Vehicle Regulation

A proposal for a revised regulation that replaces the End-of-Life Vehicle (ELV) Directive was presented in 2023 and has yet to be adopted. The proposal is supposed to replace not only the existing ELV directive but also several other directives, including the *Directive on the type-approval of motor vehicles regarding their reusability, recyclability and recoverability.*[7]

The End-of-Life Vehicle Regulation establishes requirements for the treatment of scrapped vehicles and their components. It includes circularity standards for vehicle design and production, focusing on reusability, recyclability and recoverability and integrating recycled content. These requirements are verified during the type-approval processes for vehicles. The regulation also employs information and labelling requirements on parts, components and materials.

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5. https://environment.ec.europa.eu/topics/waste-and-recycling/waste-electrical-and-electronic-equipment-weee_en#timeline
6. https://environment.ec.europa.eu/topics/waste-and-recycling/batteries_en
7. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02005L0064-20090203

Additionally, it also specifies conditions regarding extended producer responsibility, the collection and treatment of end-of-life vehicles, as well as on the export of used vehicles to countries outside the EU. Part of these requirements includes design standards that enable the easy removal and replacement of recyclable parts and components, as well as mandatory removal of certain parts and components to enhance the efficiency of CRM recycling.

Article 13 requires all new vehicles to have a digital passport similar to equivalent passports required by the Battery Directive and Eco-design regulation.

Eco-design for Sustainable Products Regulation (ESPR)

The Eco-design for Sustainable Products Regulation (ESPR) entered into force on 18 July 2024 and is the main legislative initiative of the EU towards more environmentally sustainable and circular products.[8]

The regulation defines eco-design as the integration of environmental sustainability considerations into the characteristics of a product and the processes taking place throughout the product's value chain.

The regulation establishes a framework of eco-design requirements that products must fulfil in order to be sold in the European market or put into service. The regulation provides guidelines for mandatory green public procurement requirements and creates a framework aimed at preventing the destruction of unsold consumer products.

ESPR requires products, components and materials covered by the regulation to be associated with a digital product passport with accurate, complete and up-to-date information described in ESPR and delegated acts. This information intends to support the product's sustainability and circularity, strengthen the product's legal compliance, and include instructions on disassembling products for repair and recycling. A comprehensive and detailed description of the data to be included in a digital passport will be provided by the EU Commission at a later stage.[9] The final format of the digital passport is expected to include information about:

- Product's technical performance
- Materials and their origins
- Repair activities
- Recycling capabilities
- Lifecycle environmental impacts

8. https://commission.europa.eu/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/ecodesign-sustainable-products-regulation_en
9. https://green-business.ec.europa.eu/implementing-ecodesign-sustainable-products-regulation_en

2. Measures for better CRM-resource efficiency in the Nordics

This chapter describes potential measures and instruments for increased CRM-waste prevention and reuse in the Nordics. 90 possible measures have been identified, of which 13 have been given an extended description in this chapter. A complete list of all identified measures can be found in Appendix Table 1.

2.1 Measures for waste prevention

The following sub-chapters describe possible measures for CRM-waste prevention.

2.1.1 Reduced use of helium for entertainment purposes

Table 2.1 Summary of the measure: Reduced use of helium for entertainment purposes.

Objective and intended effect/expected impact	Implementation	Feasibility and evidence
Helium is produced as a by-product of natural gas, and its supply is therefore expected to decline as fossil fuels are phased out globally. The gas has important industrial and technical applications, as well as being widely used for entertainment purposes. Banning or restricting its use for entertainment purposes would increase security of supply for more important uses. 20 % of todays helium use can be avoided through a ban on party balloons. Changes in MRI-practice can limit the helium use further.	Ban helium use in party baloons, increase collection of helium from MRI-machines and increase use of helium free MRI-machines will reduce depletion of limited helium reserves and future supply risk. A national ban on helium should be set by governmental authorities. Helium recycling from MRI-machines should be required where possible. A economic deposit on helium use for other purposes can finance recycling schemes to ensure helium recycling from other applications.	Although local iniatives have been tried out or proposed, no national action has so far been taken by Nordic countries.

Helium is considered a CRM by the EU and several other Western countries.[10] Many non-Western countries such as Russia, Qatar and Algeria have large LNG trains with associated and increasing helium extraction, while the traditional supplier USA has a falling production. Hence - the supply has for decades been considered a geopolitically important.[11] It is used in small quantities in

10. EU, USA, UK, Canada, Australia has listed helium as critical.
11. Siddhantakar et al. Helium resource global supply and demand: Geopolitical supply risk analysis. Resources, Conservation and Recycling 2023.

specialised applications such as coolants for Magnetic Resonance Imaging (MRI), semiconductor production and ICP analytical equipment. In some of these applications, it is possible to recycle parts of its use, while in others, it is not. Even when recycling is considered likely, one should expect low recovery rates, as all currently known technologies for storing and processing helium result in some continuous losses.

However, one of the largest sources of helium loss is considered non-essential: the filling of party balloons. The only application is solely for entertainment purposes, offers no critical value, and contributes to wildlife-threatening litter.

All helium supplied today is a derivative of LNG production. When natural gas is cooled to a liquid, the small trace amounts of helium within the resource become concentrated and can be further refined through cryogenic treatment. The level of helium in natural gas is linked to the presence of thorium and uranium in the same geological formation. These radioactive elements emit a constant flow of alpha particles, eventually transforming into helium. While most natural gas resources contain minimal amounts of helium insufficient for helium extraction, some natural gas deposits have concentrations sufficient to sustain a helium separation process. Since World War II, the US has been the primary source of such helium, due to a governmental critical resource support system. However, this supply is now in decline, and the US has already tapped some of their strategic reserves to cover market shortfalls in the past decade. The dominant non-Western suppliers today are Russia,[12] Qatar, and Algeria. The role of Russia in helium supply, alongside trade embargo concerns, has already led to price increases and supply uncertainties.[13] Although the US still holds sufficient reserves to meet the needs of Western countries for several years, as these reserves are replenished, it may become necessary for Western nations to seek alternative sources of supply outside the US.

There are ongoing initiatives to establish dedicated helium extraction plants from natural resources in Kenya and South Africa, and there is potential for additional virgin sources to be developed. For instance, the geothermal plants in Iceland may contribute as a minor supplier, along with geothermal projects in other European countries as they are developed. However, the costs associated with dedicated extraction from geothermal plants are expected to be significantly higher than those of helium derived from LNG, as the operational costs of these plants must be financed solely through helium production rather than as a by-product of LNG.

As most of the helium available today is a by-product of fossil energy supplied by autocratic states, and given the concerns about supply, it is prudent to consider an overall ban on using helium for specific non-essential purposes. Instead, helium could be purchased from the global market and stockpiled while it is still readily available to secure long-term supply. Stockpiling helium will also provide additional supply security while better recycling[14] solutions from MRI machines are developed.[15]

Specific statistics on helium consumption in the Nordics are unavailable, and as all supply is sourced from outside the EU, the recommendations are based on global consumption data. Even the official EU numbers are quite uncertain, as they are 10 years old and based on unspecific import/export statistics.

The best available statistics is from the US, that estimate that 16% of helium consumption is attributed to lifting gases, which is mainly for balloons. MRI machines are just ahead at 17% of the market.

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12. https://globuc.com/news/gazprom-opens-first-of-three-helium-production-lines/
13. Kramer, D. Helium prices surge to record levels as shortage continues. Physics today 2023.
14. https://www.innovationnewsnetwork.com/helium-recycling-and-conservation-can-combat-the-global-helium-shortage/37322/
15. RAPPORT 2, kapittel om helium, insert link.

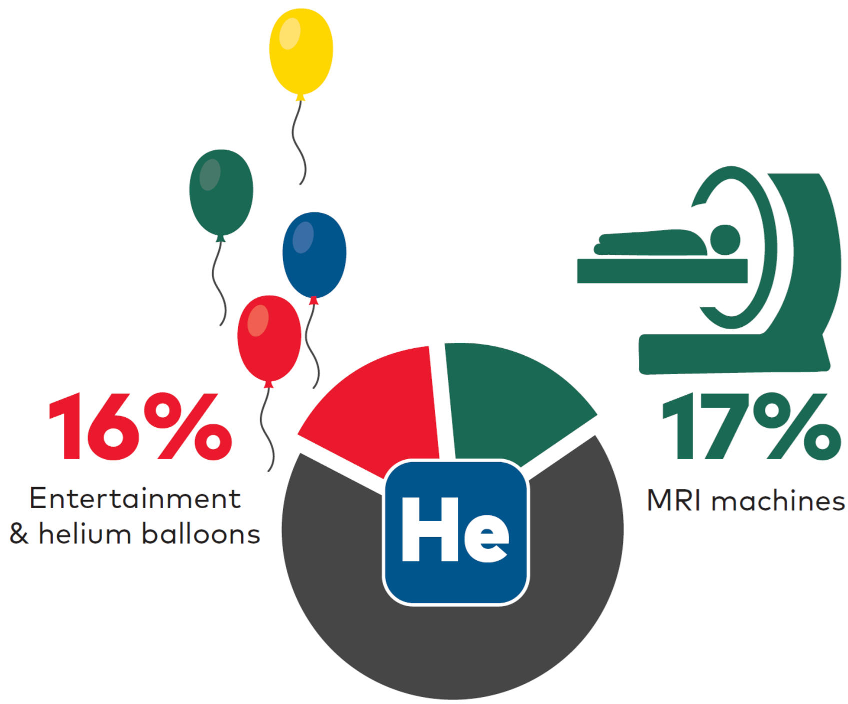

Figure 2.1 Helium consumption for party balloons compared to MRI machines. Illustration Bergfald Miljørådgivere.

Several municipalities in the Nordic countries, as well as globally,[16] have implemented or attempted to implement local bans on the sale of helium balloons, primarily due to concerns regarding littering and its detrimental impact on wildlife.[17] Additionally, there have also been calls for the establishment of national bans on such products.[18] While general bans have been proposed by NGOs and some minor political parties, it has not been lifted up as a concrete proposal by any national Government – so far.

To date, the local efforts and national proposals have yet to lead to the establishment of permanent bans. However, the forthcoming legislation under the CRMA may offer the legal justification for a ban where concerns about wildlife protection alone have not been sufficient.

Older MRI machines contribute significantly to helium loss, with an estimated loss rate of approximately 1% per operational month. While the inclusion of recycling equipment to reduce helium loss has been a common practice for many years, such systems are not universally installed and are not sufficiently efficient to entirely prevent substantial helium loss; they only serve to reduce and delay it.[19] Modern MRI machines, particularly those manufactured after 2005, use permanent magnets, which eliminate the need for helium cooling and the associated loss, or have recycling equipment. Additionally, many MRI procedures can be performed with smaller machines[20] that operate with reduced magnetic fields, such as those using permanent magnets.[21] These machines do not require helium; instead, they rely on magnets made from, e.g., neodymium, which can be recycled at the end of their lifespan.

It has been suggested that all the easily substitutable uses of helium should be banned or

16. https://www.theguardian.com/science/shortcuts/2012/dec/11/should-we-ban-helium-balloons
17. https://www.aws.org.au/wp-content/uploads/2022/10/A-ban-on-helium-balloons-is-needed-now-NSW.pdf
18. https://www.aftenposten.no/norge/i/OpWL8b/i-fjor-ba-stortinget-regjeringen-om-aa-vurdere-forbud-mot-disse-det-skjer-ikke-med-det-foerste
19. Radiological Society of North America. Keeping An Eye on the Potential Shortage of Helium for MRIs. 2022.
20. Huang et al. Portable Low-cost MRI System based on Permanent Magnets/Magnet Arrays.
21. Insinga et al. Comparison of Superconductors and Permanent Magnets for Small-scale Magnetic Resonance Imaging Devices. DTU 2024.

restricted, such as in balloons, welding gas, and leak detection.[22]

While helium-free balloons, when punctured, primarily create waste in urban areas and are often disposed of in the garbage, lost helium balloons frequently end up in nature due to their buoyancy, creating a significant threat to wildlife. For decades, conservationists have advocated for a ban on helium balloons to prevent this littering.[23]

In many of the industrial applications, helium can rather easily be replaced by argon with similar performance and price. Argon is produced as by-product from air separation, so supply will often rely on existence of such separation plants and how modern and efficient these plants are. With current downturn of major European and Nordic airgas-consuming industries such as ammonia and electronics, the argon supply might tighten and prices increase, providing challenges for using argon as substitute to helium.

Helium is also utilised in various technical applications, such as specific welding gases and gas leak detection, where many relevant substitutes are available. Substitution is therefore an option when it comes to such uses.

Potential for waste reduction of critical raw materials

Currently, approximately 16% of helium consumption is attributed to entertainment purposes, implementing a ban on such uses would profoundly affect the supply situation.

Furthermore, about 17% of helium consumption is estimated to result from losses in older MRI machines. To address this, a series of restrictions and mandates for the MRI fleet, including a replacement plan for outdated machines, recycling requirements for existing equipment, and initiatives to promote the use of non-helium technologies.

In several other applications an inert gas is needed, but helium can easily be replaced by argon, neon or other gases that is recoverable from the air.

Barriers

There should be no technical barriers to implementing a ban on helium use for balloons, and such a ban could be enforced immediately. In contrast, other applications of helium, such as welding gas, leak testing, ICP analysis, and semiconductor production, have alternative technical solutions that could facilitate substitution, given a reasonable transformation period.

However, the implementation of a ban may lead to economic consequences, such as a ban may face opposition from certain consumer groups, including families with children and young adults, due to reduced revenue for helium suppliers and retailers of entertainment equipment.

Possible means of actions/instruments

A general ban on sales of helium gas to private citizens.

A general ban on the use of helium for entertainment purposes.

Revised legislation giving municipalities legal tools for local bans against helium balloons.

100 €/kg import tax on helium, to be repaid with return of the gas to recycling.

National stockpiling of helium to protect the hospitals.

Mandate air separation plants to extract neon as helium substitute for balloons.

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22. Olafsdottir et al. Assessing the Past and Future Sustainability of Global Helium Resources, Extraction, Supply and Use- Biophysical Economics and Sustainability 2020.
23. https://www.independent.co.uk/news/science/a-ballooning-problem-the-great-helium-shortage-8439108.html

Mandate air separation plants to extract argon as helium substitute for controlled atmospheres.

Socio-economic impact

MRI equipment and other scientific and defence needs will be secured supply, keeping a significant health and security infrastructure operational long term.

Mandates for production of substitutes will increase supply of these alternative gases, such as neon and argon.

A high import tax for a product with <1% recycling will generate net income to Government.

Other variants of the measure

Other relevant measures to reduce future helium supply risks include:

Information campaigns on littering and CRM-loss of balloons if ban is not possible.

Instead of a ban, it is possible to impose a high tariff making the helium much more expensive to the balloon users while at the same time making supplies possible for MRI and other technical uses.

A general ban on using helium for welding gases and similar non-essential uses.

A Nordic Governmental or European strategic stockpile of helium for needed uses.

A considerable tariff on the import of helium to be reimbursable for all returned and recycled gas. To avoid protests from the hospital sector, it is possible to take all net income from such tariffs into a fund from which the sector can apply for funding for new or repurposed MRI machines.

2.1.2 Reduced use of aluminium for packaging purposes

Table 2.2 Summary of the measure: Reduced use of aluminium for packaging purposes.

Objective and intended effect/expected impact	Implementation	Feasibility and evidence
Significant amounts of aluminium are used as single-use packaging where alternative materials are often available. A ban or restriction on the use of aluminium for non-essential packaging purposes would reduce the overall consumption of aluminium that ends up in waste streams with limited recycling potential. As magnesium is used as an alloying additive in many aluminium alloys for packaging purposes, the same measure would also minimise magnesium consumption for the same purpose. Substitution of aluminum packaging where acceptable material alternatives exist can reduce Nordic aluminum consumption by almost 20 000 tonn anually.	Stimulate PSS-businesses reusing aluminium packaging, plates and trays. Ban the use of aluminum metallization of polymers for packaging of consumer products. Ban the use of aluminum foil for chocolate and confecionary products. Ban use of blister packaging of pills and capsules, with exceptions for medically required use. Support development of new aluminum can systems less dependent on dilution. Information campaigns to both industry and the public on most optimal use of different packaging materials. Unless introduced as a regional ban by EU, each ban should be set nationally by relevant governmental authorities.	No national initatives has so far been identifed.

Aluminium is the second most used metal in the world, acclaimed for its combination of light weight, durability and adaptability for a broad range of applications. Despite a substantial market of approximately 100 million tonnes annually, the recycling rate remains relatively low at about 35%. This is due to the short lifespan of many aluminium products, combined with the challenges of achieving full recovery, despite its substantial economic value and well-established systems for collection and recycling.

One of the primary applications of aluminium is packaging, which accounts for nearly 50% of the market in certain parts of the world. Many aluminium based consumer packaging systems, particularly those used for food packaging, are often small, damaged, or contaminated during use, making them difficult to recycle.

While some aluminium food packaging applications are well-founded, others can easily be substituted by alternative materials. For instance, two examples of unnecessary aluminium use are delivering a frozen pizza on an aluminium plate instead of cardboard or using aluminium foil to wrap a kebab when greaseproof paper could serve the same purpose.

One particularly challenging subsector is aluminium-metallised polymers and paper. These materials are commonly used in products like balloons, coffee bags, crisp bags, and candy packaging. Aluminium is deposited in thin films on polymers or paper to achieve a glossy exterior while blocking oxygen and light. Although theoretically recyclable, these composite waste fractions typically end up in Municipal Solid Waste Incineration (MSWI). Due to the extremely thin aluminium layer, most of it is lost during incineration and cannot be recovered from the ash afterwards. Given the recycling challenges regarding this group of products, full substitution should be considered.

In Norway, some major consumer goods companies have already begun transitioning away from such materials. For instance, the leading coffee producer has replaced metallised bags with improved polymer alternatives that are recyclable.[24]

In pharmaceuticals and nutrition supplement industries, pills are often packed individually in blister packs or collectively in bottles, as shown in Figure 2.2. With few exceptions, there is no chemical or medical necessity for pills to be individually isolated. The majority of pills currently sold in blister packs could be packaged in bottles instead. Observations made in Norway suggest a growing number of bottles and a declining number of blister packs, but there are no reported statistics to confirm this at the moment.

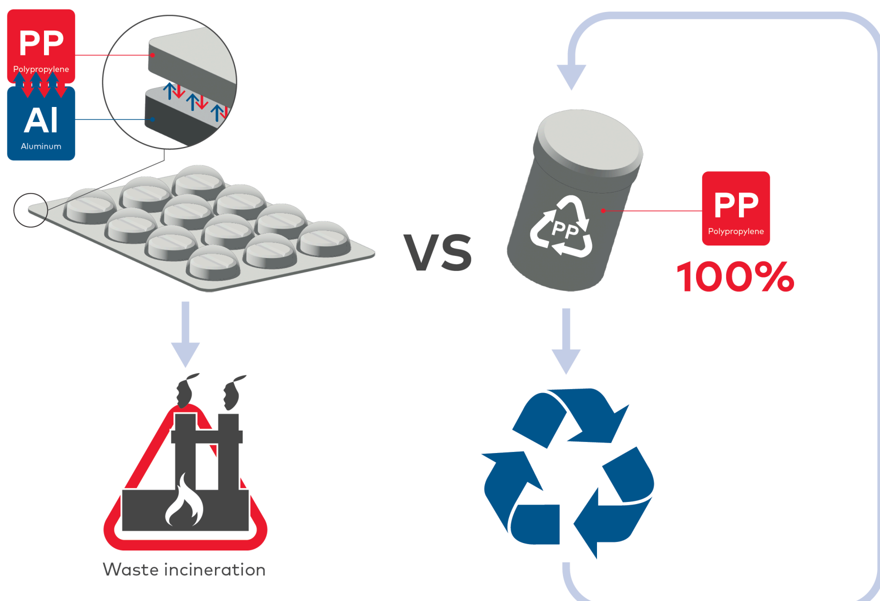

Figure 2.2 Blister packaging of pills compared to box packaging. Illustration Bergfald Miljørådgivere.

Germany faces a similar situation to the Nordic countries, with calculations estimating the potential to reduce waste by substituting blister packaging for pharmaceuticals.[25] If assumed same per capita consumption in the Nordic as in Germany, 3,000 tonnes of waste could be avoided. When nutrition supplements are included in the analysis, the number is probably significantly higher.

The largest single segment of aluminium packaging is beverage cans, mainly used for beer and soft drinks. In many markets, aluminium cans have outcompeted both glass and PET alternatives. Several studies and LCAs have compared these three beverage systems, but results vary, and no clear frontrunner in terms of environmental performance has been established across all cases. It

24. https://johjohannsonkaffe.no/vare-poser-kan-resirkuleres-som-plast/
25. Falconnier-Williams, O. et al. Untapped options to reduce waste from blister packaging for tablets and capsules. European Journal of Clinical Pharmacology 2024.

is noteworthy, however, that aluminium cans consist of three distinct alloys (the body, the top/bottom and the ring) that have different chemical composition. While aluminium cans exhibit high recycling rates, the mixing of different alloys during recycling, combined with contaminants from pigments, often degrades the quality of the recycled aluminium metal. This requires dilution with virgin aluminium and the addition of further alloying elements to maintain material properties. While there are several valid arguments in favour of the continued use of aluminium cans for beverages, the development of new alloy standards that enable higher-quality recycling should be pursued. In regions where post-consumer aluminium foils are collected and recycled, the same need for 30% to 50% dilution with virgin aluminium and alloying elements has been observed.[26]

Many short-lived aluminium products contain alloying elements listed as critical and strategic by the EU. For example, the alloy Al 1235, a standard foil, contains copper, titanium, (high-grade) manganese, and magnesium. As aluminium foil is only recycled to a minute level, it is never recycled back to foil, so these highly sought-after alloying elements are lost in an inferior casting alloy. Similarly, blister foil used in pharmaceuticals often uses alloys containing copper, manganese and magnesium.

The substitution of aluminium packaging is not straightforward in all cases. For some applications, it may be the best environmental alternative, as increased food waste or other environmental consequences might result from using less ideal packaging materials.

Some remarkable examples highlight promising solutions. Tetra Pak, for instance, has developed juice cartons that entirely substitute the aluminium barrier with natural fibre-based barriers.[27] While each juice carton contains only 1.5 grams of aluminium, this amount becomes significant when Tetra Pak supplies tens of billions of cartons. Traditionally, beverage cartons consisting of wood fibre, polymers, and aluminium have received criticism due to the challenges of recycling mixed materials and the significant climate footprint of the aluminium film. However, several other companies, in addition to Tetra Pak, are actively working on improving the sustainability of this vast market.[28]

Aluminium foil is still extensively used in chocolate and confectionary despite acceptable polymer alternatives is available. The European aluminium foil industry promotes the use of these applications with the argument that "An alufoil wrapper displays quality to the consumer".[29] However, this statement seems questionable as polymer packaging systems show comparable quality performances.

The European aluminium packaging industry claims that the recycling rate for their sector is 55%,[30] which is relatively high. However, considering that most packaging has a lifespan of perhaps three months, from the rolling mill to its return, it means that a new tonne of primary aluminium supplied to this market is lost within six months.

Potential for substitution/waste reduction of critical raw materials

Packaging is one of the largest segments for the second largest metal in the world – any implemented substitution would have a significant effect, both on aluminium consumption itself and its alloying elements.

26. Astarita, A. et al. Impact of rolling processes in the production of aluminum packaging assessed through LCA. The International Journal of Life Cycle Assessment 2023.
27. https://www.tetrapak.com/en-no/campaigns/go-nature-go-carton/sustainable-solutions/packaging/decarbonisation
28. https://www.ingredientsnetwork.com/sustainable-shift-the-rise-of-aluminiumfree-news119689.html
29. https://www.alufoil.org/confectionery
30. https://www.alufoil.org/recycling-recovery

Assuming conservatively that about 10% of the aluminium market is packaging, the Nordic countries represent 1.8% of global GDP, and 10% of excess packaging can be avoided or substituted by rather simple and non-intrusive means – it is still 18.000 tonnes of high-end aluminium alloys saved from loss through waste incineration.

Barriers

Industry resistance to protect existing markets against all change will be a key barrier.

Restrictions in Europe generally or Nordic countries specifically could result in products being packed outside of Europe and imported directly to avoid restrictions.

Possible means of actions/instruments

The following measures should be considered:

Ban the use of aluminium metallization of polymers for the packaging of consumer products.

Ban the use of aluminium foil for chocolate and confectionery products.

Ban the use of blister packaging of pills and capsules, with exceptions for medically required use.

Information campaigns to both industry and the public on the most optimal use of different packaging materials.

Socio-economic impact

Aluminium foil for packaging is costly, and most competing systems will have equal or lower cost per unit. Consequently, consumer costs will fall, and the socioeconomic effect could be positive. There are items where aluminium foil prevents food waste, and those segments should not be targeted for any measures.

Reduced aluminium consumption would also mean reduced energy consumption compared with competing materials. Reduced energy consumption may contribute to reduced power prices.

Other variants of the measure

An alternative to banning aluminium packaging is financial measures. It is possible to use a range of tariffs and taxes to achieve many of the same goals as a ban.

A very high tariff on blister packaging would, for instance, incentivise substitution with other packaging methods.

It is also possible to use tariffs as a way of funding, such as having a general tariff on rolled aluminium recovered by recycling plants when they use recovered post-consumer aluminium.

2.1.3 Eliminate the use of coke in steel production

Table 2.3 Summary of the measure: Eliminate the use of coke in steel production.

Objective and intended effect/expected impact	Implementation	Feasibility and evidence
Metallurgical coke is used as a reducing agent in the production of iron and steel. An alternative production method where hydrogen and electricity replace coke in the process is available through Direct Reduction (DRI). DRI-plants are being planned in Sweden through the Hybrit and H2Gsteel projects.	Establishment of DRI furnaces that can replace blast furnaces should receive both economic and legislative governmental support. While hydrogenbased DRI is the optimal non-emission infrastructure, even natural gas based DRI will dramatically reduce emissions – and will eliminate the need for coke. Implementation of strict CBAM tariffs around Europe, to avoid unfair competition should also be be done.	DRI-plants are operational world wide, and planned in Sweden.

Steel is the biggest metal sector, and any development here will have a more extensive influence than any other sector. Steel is also a major industry for Nordic countries, with substantial infrastructure in all steps and variants of the value chain. The Nordic countries have several iron ore mines, blast furnaces, and many speciality steel plants, steel processing plants, ferroalloy plants, and steel recycling plants. The overall investment and competence in the steel sector is significant in the Nordic countries.

Despite significant global efforts to develop and maintain a high recycling infrastructure, the global steel market is still two-thirds based on the virgin iron ore to pig/sponge iron supply. While most iron waste is sorted and recycled, our society's ambition of a circular steel industry is still far into the future.

Today, virgin iron ores are produced predominantly by reduction processes using coking coal in blast furnaces. With a steel industry based on this technology, Europe will need to produce or import large amounts of coking coal, as there is no realistic path towards replacing this coal in existing blast furnaces. The supply lines of coking coal to Europe have even been more strained since the Russian invasion of Ukraine.[31]

In Europe, the US, and China (and probably most other steel regions), there has already been a move towards electric arc furnaces (EAF), which use electricity to melt scrap steel instead of reducing iron ore. However, there is only so much iron and steel scrap available, and the qualities of scrap are often so low that dilution with virgin iron is needed.

The current iron reduction platform, the blast furnace (BF) technology, produces large volumes based on (sometimes) low-quality iron ores that are melted and reduced with metallurgical coals and cleaned with slaggifiers in a dual-phase operation. BF plants are prominent in most aspects, including production volumes, CAPEX, OPEX, energy consumption, emissions and waste

31. Sivek, M. et al. Coking coal - Really a critical raw material of the European Union? Resources Policy 2023.

production. The BFs of the world are the old workhorses of the steel industry that are still hugely present but in the last years before retiring[32] and leaving the market for new and more efficient technologies.[33] Indeed, one current positive trend is the industry transformation to direct reduction – DRI.[34]

In contrast to the BFs, direct reduction (DRI) uses high-quality iron ore pellets, which are reduced without smelting by a reducing gas, either natural or hydrogen gas. The pellets are reduced into iron or steel with minimal carbon consumption and emissions. The global fleet of DRI plants is expanding, while the construction of new BFs has dropped off.[35] Based on approved and financed plans, the European production of DR iron is expected to reach 20 million tonnes by 2030.[36]

While Sweden and Norway are important iron ore producers, and Sweden and Finland have substantial BF production, no DRI-capacity have so far been established. The Nordic region can however contribute heavily to this transformation of the European steel industry, if they decide to do so.

The Hybrit[37] and Stegra[38] projects in Sweden and Blastr[39] project in Finland could become important for the European climate policy and secure climate-neutral sponge iron for the EAFs. These projects are motivated by replacing coking coal as a reductant and energy source for producing iron and reducing the emission of greenhouse gases.

It should be mentioned that the production of steel is also dependent on the addition of alloys and that all ferroalloy plants also use coking coal in their production.[40] Indeed, even if the Nordic countries develop zero-emission DRI pig/sponge iron plants, the steel will not be zero emission if it requires non-zero emission alloys. The Nordic countries also have a large fleet of ferroalloy plants (silicon, ferro silicon, silicon carbide, silicon nitride, silicon manganese, ferro manganese, ferro chromium), and specific strategies will need to be developed for these rather specialised production technologies if Nordic steel alloy components are also to become zero or low carbon products. All of these ferroalloy plants have already stated an intent to increase the use of biocarbon, i.e. continue using existing smelter technology but replace (part) of the carbon reductant from fossil with biomass.[41] However, the lack of available biomass resources will hamper such a transition and increase the cost of feedstocks.[42] Many of these plants are also investigating other strategies, such as hydrogen, CCS or carbon looping.

Potential for substitution/waste reduction of critical raw materials

It is possible to substitute 100% of coking coal from blast furnace steel production by switching to direct reduction technology. SSAB has announced their intention to close its blast furnaces and become fossil-free with a combination of hydrogen-reduced sponge iron and EAFs.[43] As SSAB consume approximately 2,5 million tonnes of metallurgical coke for their steel plants, such a transformation will be significant at more than 90% reduction. Substitution of coking coal from

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32. Vogl V. et al. Phasing out the blast furnace to meet global climate targets. Joule 2021.
33. https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/eu-climate-targets-how-decarbonise-steel-industry-2022-06-15_en
34. Ling, J. et al. Direct reduction of iron to facilitate net zero emissions in the steel industry: A review of research progress at different scales. Journal of Cleaner Production 2024.
35. https://energyandcleanair.org/publication/turning-point-china-permitted-no-new-coal-based-steel-projects-in-h1-2024-as-policies-drive-decarbonisation/
36. https://gmk.center/en/news/global-dri-production-will-increase-to-175-million-tons-by-2030-wsd/
37. https://www.hybritdevelopment.se/en/
38. https://stegra.com/the-boden-plant
39. https://www.blastr.no/BusinessAreas/
40. Tangstad, M. et al. Coal-based reducing agents in ferroalloys and silicon prod. New Trends in Coal Conversion 2019.
41. Syrrup, G. et al. Charcoal as an Alternative Reductant in Ferroalloy Production: A Review. Processes 2020.
42. https://www.ieabioenergy.com/wp-content/uploads/2020/01/IEA-Bioenergy-Task-Lignin-as-a-met-coal-substitute-December-2019-Final-191218-1.pdf
43. https://www.ssab.com/en/company/about-ssab/the-earth-calls-for-action

the ferroalloy plants will only be possible in the future as substantial technological developments need to take place.

Barriers

A significant barrier has been the huge sunken investments into the fleets of blast furnace infrastructure. As the blast furnace technology is decided to be replaced, another barrier may be conservative national policies to keep old and inefficient furnaces operating instead of supporting investments in new carbon-free technology.

The reduction of coke-free iron will require more electricity and stable sources of electricity. If no long-term large scale electricity supply is available, it will be impossible to build new Nordic DRI plants. DRI technology also requires high-quality magnetite iron ore, a product in limited supply. The dominating producer of this quality in the world market is, at present, Sweden.

Possible means of actions/instruments

Support the establishment of DRI reduction furnaces that directly replace and substitute BFs. While hydrogen-based DRI is the optimal non-emission infrastructure, even natural gas-based DRI will dramatically reduce emissions and replace all coking coal consumption.

Support the implementation of strict CBAM tariffs around Europe to avoid unfair competition.

Support the establishment of increased production of high-grade magnetite ore to secure feedstock for future coke-free steel plants.

There is also specific competition regarding the location of future DRI plants in Europe, and large countries such as France and Germany have provided substantial public guarantees and financing in support. If the Nordic countries want to attract investments into DRI plants – similar support schemes should be implemented.

Socio-economic impact

The steel industry of Europe and the Nordic countries is still large and important. The conversion of old to new technology for iron reduction will protect jobs in the whole value chain and even support increased recycling of iron scraps. However, the European steel industry must be protected against unfair competition, for example, through CBAM mechanisms.

Other variants of the measure

Historically, and in most countries, large steel plants have been built by the Government directly or through cooperation between a State and a private company. Emission-free, resource-efficient steel plants could be financed and built the same way.

Support the development of the Electric Arc Furnace (EAF) supply line with improved steel sorting technologies. EAFs do not need investment support, but the value chain needs support to improve scrap qualities.

2.1.4 Adopt alternative technology for the primary production of aluminium that eliminates the need for fluorine and anode graphite

Table 2.4 Summary of the measure: Adopt alternative technology for the primary production of aluminium that eliminates the need for fluorine and anode graphite.

Objective and intended effect/expected impact	Implementation	Feasibility and evidence
A number of alternative processes for the production of primary aluminium that could result in increased recycling or reduced need for CRMs as feedstocks are under development. Aluminium production using inert anodes would limit the need for graphite in the process, aluminium production with anorthosite would yield pure silica as a by-product, and aluminium production based on a chlorine-based salt melt would eliminate the need for fluorine for the same purpose while also enabling the extraction of trace amounts with CRMs other than aluminium. By supporting the development of these technologies, aluminium production could become far more CRM resource efficient.	Governmental support for pilots and demonstration plants for alternative production of primary aluminium. Governmental economic support schemes should be considered either thorugh CAPEX payments or loans/ grants.	Technolgies have been tested in pilot plants

Aluminium is the second most important metal in the world after iron and steel. The global aluminium market is about 100 million tonnes, of which about 30 million tonnes are recycled post-consumer metal, while 70 million tonnes is primary metal. The Nordic countries represent a strong cluster for baseload production and technological innovation. The Nordic annual primary aluminium production is approximately 2,3 million tonnes. In addition to this comes high-end refining, recycling and alloying.

Although the Alcoa process and other incremental improvements are in use, most of the primary aluminium production today continues to rely on the original Hall-Héroult process, a technology developed over 100 years ago. This process begins with the primary raw material, bauxite, which, is refined into aluminium oxide and subsequently dissolved into molten cryolite (Na_3AlF_6). The Hall-Héroult process is energy-intensive, consuming approximately 30 TWh of the Nordic power production to sustain the high operating temperatures required. It also requires substantial use of other CRMs, such as graphite and fluoride. Despite its industrial significance, the process is a serious source of GHG emissions and pollution. For every kilogram of aluminium produced, 1,2 kilograms of carbon dioxide are emitted alongside other harmful by-products like hydrogen fluoride and carbon monoxide that escapes the smelter. Additionally, bauxite mining contributes to the destruction of vast areas of pristine forests in ecologically sensitive regions and generates significant quantities of hazardous waste. The combination of high energy demand, substantial GHG emissions, and environmental degradation underscores the urgent need for sustainable advancements in aluminium production technology.

Historically, several alternative technologies have been used for primary aluminium production, but most of these have been outcompeted by the Hall-Héroult process. However, advancements in process optimisation have brought some of these older technologies to a new level of maturity. One such technology is the HAL-ZERO technology[44] promoted by Norsk Hydro. This method involves processing aluminium oxide into aluminium chloride, purifying it, and then using electrolysis to produce primary aluminium while recycling the chlorine. The HAL-ZERO technology is currently being tested in a pilot plant in Norway and is rooted in the chlorination technology originally developed by Alcoa in the 1950s.[45] While details remain proprietary, the updated chlorination process significantly differs from the original Alcoa approach, partly inspired by Norsk Hydro's extensive experience with magnesium chloride electrolysis. If industrialised, this technology could eliminate the need for CRM fluoride.

Another advantage of the chloride-based approach lies in its ability to achieve high-purity aluminium and utilise wastes as feedstock. It is much easier to increase the purity of aluminium chloride before electrolysis compared to aluminium oxide before traditional Hall-Héroult processing. This enables the use of a broader range of feedstock, including low-cost anorthosites, kaolins, and mineral byproducts from the mining industry. For instance, tests conducted in China have demonstrated that relatively simple process steps can dissolve coal fly ash[46] in hydrochloric acid, with aluminium chloride extracted and refined to an impressive 99.98% purity.[47] Achieving similar purity levels in Hall-Héroult processing requires expensive and energy-intensive refining after electrolysis. This enhanced purification potential also opens the possibility of a shift away from bauxite sourced from tropical forests of Brazil and Western Africa. Instead, alternative feedstocks, such as ashes from municipal solid waste and bio-CHPs could be utilised. With such a technological transformation, the use of both CRM fluoride and bauxite will be eliminated.

Even if bauxite remains the preferred raw material for aluminium production after advancements in electrolysis technologies, significant changes will be feasible for the pre-processing stages. Currently, bauxite processing is the sole source for certain CRMs, such as gallium and scandium, and is also essential for the supply of other CRMs.

The aluminium oxide produced today through the Bayer liquor process typically achieves a purity level of around 99%, with high levels of non-CRMs such as sodium, calcium and iron, and even residual amounts of gallium, germanium, lithium, rare earth elements and other CRMs. If this 99%-pure aluminium oxide was used as feedstock in chloride-based technologies, the inclusion of an intermediate refining step could enable the extraction of some of these contaminants. This would, in one step, both facilitate an important CRM production and result in higher-quality primary aluminium with reduced energy consumption compared to current methods. Furthermore, a chloride-based value chain could avoid the Bayer Liquor step and instead digest directly.[48] However, this approach would increase the consumption of chlorine and generate iron chloride as a by-product.

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44. https://www.hydro.com/no/global/media/pa-dagsorden/veikart-for-nullutslippsproduksjon-av-aluminium/halzero--zero-emission-electrolysis-from-hydro/
45. Yan et al. Molten salt electrolysis for sustainable metals extraction and materials processing – a review.
46. Cheng et al. Experimental investigation on the direct crystallization of high-purity $AlCl_3·6H_2O$ from the $AlCl_3$-$NaCl$-H_2O(-HCl-C_2H_5OH) system. Hydrometallurgy 2019.
47. Chen et al. Preparation of high-purity crystalline aluminum chloride based on aluminum separation from circulating fluidized bed fly ash. Powder Technology 2024
48. Vollheim et al. Process Techniques for AlCl3-production from bauxite. Proceedings of The Electrochemical Society 1986.

Switching from fluoride-based to chloride-based electrolysis will also reduce energy consumption. While the Hall-Héroult process on average consumes 13,4 kWh per kilogram of aluminium, chloride-based technologies operate at lower temperatures and consume only 9,6 kWh per kilogram.[49] This power efficiency gain represents 9 TWh for the whole of the Nordic primary aluminium fleet if transformed fully. In principle, this liberated power capacity could allow for an increase in aluminium production from the current 2,3 million tonnes to over 3 million tonnes, thereby increasing European self-sufficiency without the need for additional power plants.

Potential for substitution of critical raw materials

Fluoride consumption in the traditional Hall-Héroult process varies across plants and over time. While most fluoride ends up in SPL, dust, and dross, a smaller portion is lost as emissions to air and water. Assuming an average consumption of 7,5 kg of fluorine per tonne of primary aluminium produced, this represents an annual consumption of approximately 17,400 tonnes by the Nordic aluminium industry. Transitioning to alternative technologies will eliminate this consumption, along with the associated waste and emissions.

It is also possible to substitute the feedstock from virgin bauxite mined in the Amazon to mineral by-products and ashes currently landfilled in the Nordic region. However, this will require more advanced pre-processing. Fully implemented, it is possible to substitute bauxite altogether.

Barriers

The main barrier seems to be industrial conservatism, which makes primary aluminium producers hesitant to leave the Hall-Héroult process behind. Capital investments into primary aluminium production are high, with any new plant costing billions. New technologies, such as chloride electrolysis, are expected to have CAPEX comparable to the Hall-Héroult technology. If considering that the whole value chain will be influenced, one should take into consideration that the global aluminium industry represents sunk investments of ballpark 1 trillion US$,[50] a capital base that cannot be easily replaced.

Environmental regulations might be a barrier on one issue. The use of chlorine will create a risk of producing chlorinated toxins. Process optimisations and proper off-gas treatment can mitigate this.

Possible means of actions/instruments

Even if most of the technology has been tested already, there are always issues with operational details that need pilot operations to clarify. These pilots and all kinds of pre-treatment development should receive proper R&D support.

Substantial CAPEX support, either through loans or grants, should also be considered.

Socio-economic impact

Much of the Nordic primary aluminium fleet is rather old and has high OPEX compared to newer and larger plants in China and the Arab countries. New plants with improved and more energy-efficient technology that generate less waste and emissions, deliver higher metal grades, and reduce CRM supply risks will strengthen competitiveness and continue providing tax revenue and employment.

The aluminium industry is one of Iceland and Norway's top three export sectors.

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49. https://blog.sintef.com/sintefenergy/energy-efficiency/could-the-chloride-process-replace-the-hall-heroult-process-in-aluminium-production/
50. McKinsey 2022. Aluminum decarbonization at a cost that makes sense.

Other variants of the measure

Two alternative ways to reach the fluoride-free primary aluminium production goal are carbothermic reduction[51] and the use of inert anodes. Major corporations have extensively tested these technologies over time, each offering distinct advances and some hard-to-solve constraints.[52] While the technological principles are established, they have yet to be competitive with sunk-cost Hall-Héroult plants that allow unrestricted CO_2 emissions. Nevertheless, both technologies play a crucial role in reducing and replacing fluoride while aiming to eliminate all CO_2 emissions. However, both technologies are based on the current upstream supply of aluminium oxide from the bauxite-Bayer liquor value stream and should be considered for governmental support.

Aluminium chloride is a significant product with an estimated global market of 1,5 million tonnes. Its primary application is as a coagulant in water treatment. Recently, plans for a new large-scale production plant to be established have been announced in northern Sweden.[53] Historically, the development of industrial clusters - where expertise and materials develop in parallel – has been shown to increase competitiveness.

2.1.5 Reduced use of copper for chemicals

Table 2.5 Summary of the measure: Reduced use of copper for chemicals.

Objective and intended effect/expected impact	Implementation	Feasibility and evidence
Thousands of tons of copper metal are removed from secondary value chains in the Nordic countries to become preservatives, biocides and pigments. This copper cannot be recycled, although some of the copper is found in incineration ashes. There are good substitutes for many of these applications. A ban or restrictions on the use of copper-based preservatives, biocides and pigments would not only minimise the Nordic consumption of copper by as much as 16 000 tons anually, but can also contribute to an increased copper recycling rates.	The following restriction should be considered: Ban against the use of copper for timber preservative, with some possibility of legal exemptions. Ban against the use of copper for fish farming infrastructure. Ban use of copper fungicides for non-essential farming, such as flowers and Christmas decorations. Ban the use of copper and all other CRMs in printing inks, textile dyes and pigments for polymers and paints. Tariff or tax on use of all legal copper chemicals to increase price and incentivise reduced consumption should also be considered. Information campaign that raises public awareness about the negative CRM-implications of copper chemicals.	No national initatives has so far been identifed.

51. Kvande et al. The Aluminum Smelting Process and Innovative Alternative Technologies. JOEM 2014
52. https://blog.sintef.com/sintefenergy/energy-efficiency/aluminium-electrolysis-using-inert-anodes/
53. https://www.arctictoday.com/wibax-wants-to-build-aluminum-chloride-factory/

Copper is one of the most essential metals for the green transition due to its natural properties, such as high durability, thermal and electrical conductivity, and corrosion resistance. Being crucial for the development of human society, the demand for copper will significantly increase in the future.[54] Not all current applications of copper however align with a circular and sustainable economy.

Current annual global production of primary copper is around 26 million tons,[55] and recycling adds around 9 million tons of secondary copper to the global market.

the International Copper Association estimates that the global annual demand for copper will increase further by 12,6 million tonnes[56] to support the ongoing energy transition. As the Nordic countries represent 1,79% of global GDP, this corresponds to a requirement of 225,000 tonnes of increased primary and secondary copper production or reduced consumption. Given the Nordics' position as a copper mining region, home to significant copper processing infrastructure, and a frontrunner in renewable energy and electrified transport, it is reasonable to expect the Nordics to contribute more than only its relative share to future supply.

Copper is the third most used metal in the world after iron and aluminium and is also the oldest of all anthropogenic metals. Humanity has used copper for various purposes for 8,000 years, and almost 80% of all copper ever extracted remains in use today, due to its high value and easy recycling. The long history humanity has had with copper and the many interesting features it provides has generated thousands of different applications, including many as alloys and chemicals.

Although copper has a relatively high recycling rate with a European end of life return input rate of 30%,[57] there is a substantial structural loss of copper due to insufficient sorting and recycling solutions, causing copper components and wiring to end up in steel and aluminium. While insufficient sorting and recovery technologies can be improved, some copper applications are inherently designed in a way that results in unavoidable metal loss. Some of these applications consume copper equivalent to the output of several mid-sized copper mines.

One such application is the use of copper in timber preservation for outdoor purposes. Over time, copper has become a dominant chemical for this purpose, replacing previously used chemicals such as CCA and creosote, which have been banned for health and environmental reasons. Copper compounds has proven to be cost-efficient and reliable for this purpose, although leading to systemic loss of this crucial metal.

In the Nordic countries, the production and use of copper for timber preservation significantly surpasses that of other parts of Europe, partly due to timber-based construction traditions. While it is possible to recycle some of this copper through proper collection, incineration and processing of ashes, this represents only a small fraction of the copper initially utilised. Most of the copper is lost over the lifespan of the timber product, either leaking out of the wood or not being collected as waste for recycling.

Currently, several alternative technologies can substitute copper in all wood preservation applications. Based on different requirements, it is possible to substitute with chemicals such as acetic acid,[58] furfuryl alcohol[59] or linseed oil, or by using thermal[60] and mechanical treatments.

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54. IEA 2024. Global copper demand in the Net Zero Scenario, 2023-2040
55. https://rmis.jrc.ec.europa.eu/rmp/Copper
56. https://internationalcopper.org/resource/regional-trends-and-the-green-energy-transition-are-expected-to-increase-global-copper-demand-by-12-6mt-from-2020-to-2040/
57. https://rmis.jrc.ec.europa.eu/rmp/Copper
58. https://www.accoya.com/acetylation-what-is-it-and-what-is-acetylated-wood/
59. https://kebony.com/no/
60. https://thermory.com

Consumption of copper-treated timber can also be minimised by limiting the use of treated timber to only applications where it is needed. Other materials made of metals, ceramics or painted surfaces can replace some of the currently copper-treated wood.

In Norway, there has also, for decades, been a substantial use of copper to preserve cages for fish farming. While the industry has made significant efforts to reduce loss and emissions and promote substitution and recovery of this copper, the net consumption is still substantial.[61] It is possible to avoid copper use altogether by replacing fish farming nets with solid, sea- or land-based constructions.

Copper has been used in pigments for centuries[62] and remains a standard component of hundreds of different pigment systems. While copper sulphate is the primary historical pigment compound, there are now also a lot of other organic copper compounds used as high-grade pigments. While some of these applications are protected and mandated by cultural heritage - particularly in the preservation of historic buildings and artwork - such considerations do not extend to new construction or art. Although the overall volume of copper used in paints is small compared to other sectors, it can, with a few exceptions, not be classified as essential.

Copper is also frequently used in dyes of cotton and other fabrics, partly for achieving specific colour spectra but also for antibacterial properties.[63] This copper content is lost over time, both during dyeing and later through the use of the fabric, especially when washing (hence found in grey water)[64] and in the textile waste – either incinerated in the Nordic or exported for landfills in continental Europe.

Copper fungicides are used in various applications, from flowers to fruits – and are even accepted in organic farming. As the plant protection market is already heavily regulated and the number of working alternatives is few and far between for both organic and conventional farmers, restrictions on this use are probably not feasible. Globally, copper fungicides are a vast market, and a proportional part is most likely consumed in the Nordics.

Smaller amounts of copper are used in health and cosmetics products, most notably in skin creams.[65]

In Norway, about 20,000 tonnes of high-quality copper scrap is removed from metal recycling supply lines and reacted to copper oxides for use as feedstock into these different fungicides, bactericides, molluscicides and pigments.[66] While this process utilises recycled copper, it effectively removes this material from potential real recycling cycles.

The role of copper as an alloying element is also noteworthy from a substitution perspective, particularly as some substitutions have already been implemented in certain cases.

In many parts of the world, copper is still used in coinage. In the Nordic countries, the use of cobber in currency production has almost entirely ceased, as electronic payment systems now dominate. This is one example of a market-driven substitution with a substantial impact on CRM availability – without costs or negative attention.

Two other traditional applications of copper that have experienced market-driven substitution are water piping and roofing. In both cases, the implementation of polymer and elastomer-based

61. https://www.hi.no/hi/nyheter/2023/januar/kobber-fra-fiskeoppdrett-har-trolig-negativ-miljoeffekt
62. Švarcová, S. et al. Micro-analytical evidence of origin and degradation of copper pigments found in Bohemian Gothic murals. Analytical and Bioanalytical Chemistry 2009.
63. Shahid, M. et al. Copper-Treated Environmentally Friendly Antipathogenic Cotton Fabric with Modified Reactive Blue 4 Dye to Improve Its Antibacterial and Aesthetic Properties. Coatings 2023.
64. Baughman, G. Fate of copper in copper-complexed dyes during biological waste treatment III. Dyes and Pigments 2001.
65. Borkow, G. Using Copper to Improve the Well-Being of the Skin. Curr Chem Biol . 2014
66. https://nordox.no/

alternatives has been increasing the market share driven by the lower cost and, to some extent, easier maintenance.

Potential for loss prevention/substitution of copper chemicals

Based on European[67] and American[68] analysis of copper flows, it can be estimated that at least 10% of the copper consumption is for end-use markets where the copper is not easily recycled and is almost always lost. At least a third of this copper consumption can potentially be eliminated by substituting with other chemicals, reducing consumption or technology changes. Based on the current GDP and copper material flow of the Nordic countries, complete substitution or elimination of these non-essential applications represents consumption of about 16,000 tonnes of copper per year that can potentially be avoided.

Barriers

There is a substantial vested interest in the current uses of copper chemicals that will protect their interest against perceived interference. European authorities experienced this resistance when they considered substitution of several of the copper chemicals under the REACH CfS-system.[69][70]

Many technologies replacing copper may be significantly more expensive, either at the purchase point or due to lifetime costs.

Possible means of actions/instruments

CRMA considerations should be coordinated with other legal frameworks. If a compound is considered for restrictions under the REACH requirement, the criticality of containing elements should be included as a determining factor.

Ban against the use of copper for timber preservatives, with some possibility of legal exemptions.

Ban against the use of copper for fish farming infrastructure.

Ban against the use of copper fungicides for non-essential farming, such as flowers and Christmas decorations.

Ban the use of copper and all other CRMs in printing inks, textile dyes and pigments for polymers and paints.

Tariffs or taxes on the use of all legal copper chemicals increase the price and incentivise reduced consumption.

Information campaign that raises public awareness about the negative CRM-implications of copper chemicals.

Socio-economic impact

It is assumed that most of the market for preserved wood is independent of preservation technology. However, wood preservation based on copper-free alternatives is more expensive, reducing some marginal market segments.

A production plant in Norway converting 20,000 tonnes of scrap metallic copper to

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67. https://internationalcopper.org/sustainable-copper/about-copper/cu-demand-long-term-availability/stocks-flows/
68. https://pubs.usgs.gov/periodicals/mcs2024/mcs2024-copper.pdf
69. Slunge, D. et al. The implementation of the substitution principle in European chemical legislation: a comparative analysis. Environmental Sciences Europe 2023.
70. The European Copper Task Force 2023. The revision of the CLP Regulation changes the applicability of the criteria for classifying copper salts as Candidates for Substitution.

non-recyclable chemicals might need to be closed. In such a scenario, 20,000 tonnes of scrap copper will be available for the circular economy.

Other variants of the measure

As this chapter proposes a range of measures, it is possible and necessary to implement any or all of these individually. Indeed, implementation will involve several legislations with only a limited amount of copper savings per measure.

2.1.6 Reduced use of rare earth elements (REE) for pigment, ceramic products and glass production

Table 2.6 Summary of the measure: Reduced use of rare earth elements for pigment, ceramic products and glass production.

Objective and intended effect/expected impact	Implementation	Feasibility and evidence
Thusands of tons of REE are being used in glass and ceramics worldwide as pigment where these CRMs are lost for future recovery. A ban or tax on the use of strategic REEs like neodymium and praesodymium in pigments, glass and ceramics could minimize the proportion of these REEs used for this purpose, and thus reduce supply risks for more essential high-tech applications.	A Nordic ban on strategic REE in glass and ceramics will have limited effect. In stead such restrictions on a European level should be proposed. Restrictions on neodymium and praesodymium are especially important.	No national or regional initatives has so far been identifed.

While CRMs such as Rare Earth metals have become well known for their high efficiency in specific key applications – they also have several non-essential uses that could easily and without significant socio-economic consequences be substituted. This will free up volumes for high-priority applications. Indeed, while REEs are now unavoidably needed for electrification, digitalisation, and modern defence technologies, the same elements are also used to colour toilet seats, glossy magazine paper and many other purely aesthetic purposes.

Indeed, REEs have been used for pigments and additives in mass-produced ceramics and glass – for purely aesthetic reasons[71] for about a century. These uses are possible to ban, restrict or tax – with resulting positive consequences for society.

When used in glass and ceramics, the REEs are sintered or glassified and will be impossible to recover later, even with very aggressive extraction techniques.

71. https://ceramicartsnetwork.org/daily/article/Using-Rare-Earth-Oxides-as-Ceramic-Colorants-to-Obtain-Intense-Colors

Figure 2.3 Examples of neodymium and praseodymium used as an aesthetic colouring in the glass. Photo: AdobeStock.

It is important to note that REEs are always present together as a group of elements, although the composition of the group differs significantly. While some of the REEs, such as neodymium dysprosium and terbium, are regarded as highly strategic and in deficit, there is a large structural oversupply of lanthanum, cerium and yttrium, and, to some degree, some of the other elements, such as samarium and europium. Indeed, while it is prudent to discuss bans or other restrictions on the use of the REEs with supply restrictions, it should be possible for some of the applications to actually substitute with other REEs.[72] Hence, any restriction or incentives must be targeted on specific elements and not on the whole group of REEs.

CRMs are used in high-volume ceramics such as tiles, bricks, sanitaryware, tableware, and mass-produced decorations. For the segment that is considered hard to substitute, the global consumption is 400,000 tonnes,[73] indicating a Nordic consumption of 7,000 tonnes. These figures include CRMs like antimony, barium, cobalt, fluorine, lithium and tungsten and vanadium – but also hundreds of tonnes of REEs such as praseodymium, cerium and yttrium. In the case of praseodymium, the reason for classifying this as challenging to substitute is that the praseodymium -pigments give specific colours that are not possible to generate with other combinations of metals.

72. Monròs et al. Ecofriendly High NIR Reflectance Ceramic Pigments Based on Rare Earths Compared with Classical Chromophores Prepared by DPC Method. Advances in Ceramics 2022.
73. García-Ten et al. Critical raw materials in the global high-throughput ceramic industry. Sustainable Materials and Technologies 2024.

Figure 2.4 Expensive ceramic toilets made with praseodymium pigments. Illustration Bergfald Miljørådgivere.

If restrictions are established for non-essential applications of REE such as pigments in toilets and tiles – hundreds of tonnes of the most critical CRM can be avoided.

While the use of REEs and other CRMs used in glass and ceramics can never be recovered, this is different for the use in printing inks[74] for paper or colourants for plastic and rubber. When such products end up in waste, they are incinerated and end up in ashes. Although challenging and expensive, extracting these CRMs from the ashes is possible, but substitution will be easier and more cost-efficient than recovery and recycling.

It is worth noting that several REE-based pigments were considered green solutions only a few years ago, as they gradually substituted environmental toxins[75] such as arsenic, cadmium,

74. Enríquez et al. Advances and challenges of ceramic pigments for inkjet printing. Ceramics International 2022.
75. Karasu et al. The recent developments in ceramic glazes. Seramik Türkiye 2020.

mercury and lead[76] in various pigment systems.[77] However, any substitution of pigments must be undertaken with caution. It is important to ensure that a CRM-motivated substitution does not lead to reintroduction of environmental toxins.

Potential for waste reduction of critical raw materials

The non-essential use of REEs of EU in glass, particularly neodymium, praseodymium and terbium, but also to a minor degree dysprosium, lanthanum, cerium and other REEs, is estimated at 500 tonnes per year. As the GDP of the Nordic countries is 10% of the European GDP, it is fair to estimate that the REE-content in the Nordic consumption of ceramics and glass is about 50 tonnes per year.

Barriers

The bulk of REE-containing ceramics and glass use is produced outside of the Nordics. Hence, the products are imported. This will make a specific Nordic legislation challenging to implement, and a European solution should therefore be sought.

Numerous applications of REE pigments have been motivated by the substitution of environmental toxins, and such toxins will, for many suppliers outside of Europe, be the fall-back solution if CRMs and REEs are restricted.

Possible means of actions/instruments

Propose the development of EU-wide restrictions on the use of CRMs in mass-produced ceramics and glass – unless it can easily be recycled.

Propose an immediate EU-wide ban on the use of Strategic CRMs in mass-produced ceramics and glass – unless they can easily be recycled.

Ban the use of strategic REEs for all uses, such as pigments and colourants, as well as paper, plastic, and rubber.

Support R&D into development of new, non-toxic pigments and colorants made from surplus REE elements.

Socio-economic impact

Reduced use and loss of strategic REEs should increase their availability for critical electrification and renewable energy needs. With increased availability or reduced consumption, assuming a small price decrease is reasonable.

CRM-based pigments for glass and ceramics are generally more expensive than CRM-free pigments. Avoidance of a few colour spectrums in toilets and tiles is assumed to have no significant socio-economic impact.

Other variants of the measure

The most ambitious measure would be a total ban on non-essential use of any CRMs, with the caveat that exceptions can be made after application.

The mildest measure would be to limit it to only banning praseodymium in ceramics and neodymium in glass.

76. Jansen et al. Inorganic yellow-red pigments without toxic metals. Nature 2000.
77. Sreeram et al. Use of mixed rare earth oxides as environmentally benign pigments. Dyes and Pigments 2008.

2.1.7 Reduced use of CRMs for fireworks

Table 2.7 Summary of the measure: Reduced use of CRMs for fireworks.

Objective and intended effect/expected impact	Implementation	Feasibility and evidence
Restrictions on fireworks could reduce the use of barium, magnesium and strontium, and thus improve the security of supply of the same raw materials for high-tech applications.	A national ban on fireworks should be introduced. Alternative an additional tax on fireworks that limit consumption or information campaign that raises public awareness about negative CRM-implications and littering problems caused by fireworks.	Countries such as Ireland and Chile , along with the U.S. state of Massachusetts , have enacted a general ban on all private use of fireworks.

Several CRMs are used in fireworks. While the energy mainly comes from non-CRM potassium nitrate or black powder, the colours are dominated by CRMs. Barium gives the green, strontium the deep red and copper produces blue. These colours are adjusted with finer tones from other CRMs such as magnesium, titanium, aluminium, arsenic, fluoride, boron, bismuth and zirconium, as well as the yellow from the non-CRMs sodium.[78] Although some rare earth elements[79] have been proposed for use in fireworks, there is currently no substantial evidence demonstrating their practical implementation.

Fireworks is a product segment in which it is impossible to foresee any relevant level of recycling. While the nice colours exist in the sky for a short moment, the elements creating the colours are dispersed and lost immediately. With no possible path towards recovery and recycling, fireworks should be replaced either with non-CRM elements or by other means of entertainment – such as lanterns or laser shows.[80]

Fireworks are already under pressure due to increased environmental[81] and safety restrictions. In fact, they are primarily banned in some regions. Emissions of environmental toxins, irritants and radionuclides[82] (contaminants from the use of radiobarite pegmatites) will likely legitimise increased restrictions.

Globally, the sale and use of fireworks are heavily regulated, with many cities and municipalities implementing partial or complete regional bans. Several towns have introduced laser shows as an alternative, aiming to prevent private use of fireworks.[83] Countries such as Ireland[84] and Chile,[85] along with the U.S. state of Massachusetts,[86] have enacted a general ban on all private use of fireworks.

Banning fireworks does come with the risk of increased smuggling and illegal distribution of fireworks.

78. https://www.usgs.gov/media/images/what-minerals-produce-colors-fireworks
79. Sturman, B. The Rare Earths As Possible Flame Color Agents. Journal of Pyrotechnics 1999
80. https://www.telegraph.co.uk/politics/2024/10/10/labour-mp-calls-replace-bonfire-night-fireworks-laser-shows/
81. Steinhauser et al. Heavy metals from pyrotechnics in New Years Eve snow. Atmospheric Environment 2008.
82. Steinhauser et al. Do pyrotechnics contain radium? Environmental Research Letters 2009.
83. https://www.govtech.com/civic/fireworks-cities-are-replacing-a-longtime-tradition-with-tech
84. https://www.citizensinformation.ie/en/justice/criminal-law/criminal-offences/the-law-on-fireworks/
85. https://www.bcn.cl/leychile/navegar?idNorma=29291
86. https://www.cityofboston.gov/images_documents/Summary%20of%20Massachusetts%20Fireworks%20Law_tcm3-51599.pdf

Figure 2.5 350 tonnes of dangerous fireworks seized in Germany and the Netherlands. Photo: German Regional Police (Landespolizei Osnabrück)[87]

Potential for substitution of critical raw materials

There are no estimates on the tonnage of these elements in the Nordics. However, an estimate from the UK[88] suggests a consumption of approximately 250 tonnes per year. Based on the relative size of GDP and population, it is reasonable to assume that the Nordic countries consume around 140 tonnes of CRMs. While this volume is relatively small compared to the larger quantities of these CRMs found in industrial waste, it is noteworthy that the consumption is conflicted for several reasons, and recycling is not possible.

Barriers

There are no barriers against a general ban on fireworks other than the infringement it introduces to personal liberty.

Possible means of actions/instruments

A calculation report on the tonnes of CRMs and other materials lost and millions of euros spent on fireworks in the Nordic should be produced as a material foundation for later proposed restrictions.

87. https://www.europol.europa.eu/media-press/newsroom/news/350-tonnes-of-dangerous-fireworks-seized-in-germany-and-netherlands
88. https://axial.acs.org/earth-space-and-environmental-chemistry/can-we-soon-launch-more-eco-friendly-fireworks

There are three main ways to structure new restrictions on fireworks:

1. Total ban on all fireworks. Entertainment to be substituted by non-chemical technologies. All issues concerning littering, pollution, health, safety, fire risk, supply risks and circularity issues will be solved.
2. Ban on use of CRMs in fireworks/full chemical substitution. This will result in different colours than today and generally more weak visual impressions, with only the CRM supply risk issue solved. Environmental and safety issues will remain unmitigated.
3. Use of fireworks only for trained professionals with a certificate from fire safety authorities. This will reduce littering and pollution, safety and fire risks. It will likely reduce the volume of CRMs.
4. As restrictions on use of fireworks is likely to increase illegal import and distribution, police and customs authorities should increase the number of controls and inspections that may reveal such activities.
5. Additional tax on fireworks that limit consumption
6. Information campaign that raises public awareness about negative CRM-implications and littering problems caused by fireworks.

Socio-economic impact

The global trade in fireworks is several billion US$, with more than 70% of products coming from China. Any type of restriction on the sale of fireworks should decrease this trade and hence, also reduce the trade imbalance with China.

International statistics indicate injuries from the use of fireworks at 2.37 per 100,000 inhabitants per year.[89] These injuries include all levels that need medical attention as well as fatalities. The occupation of medical capacity resulting from it is a cost that in the Nordic is entirely covered by Government and hence taxpayers.

Other variants of the measure

Most initiatives to regulate fireworks have ignored the CRM/resource perspective – the focus has been on fire risk, injuries and environmental harm. However, every kind of restriction on fireworks that actually brings the consumption down will have a CRM effect.

General restrictions on the use of fireworks in inner cities all over the Nordics combined with municipal investments into laser shows.

89. Bitter et al. Firework injuries are increasing in the United States: An analysis of the National Emergency Department Sample. J Am Coll Emerg Physicians 2021.

2.1.8 Reduced use of critical raw materials in small electronics in consumer products

Table 2.8 Summary of the measure: Reduced use of critical raw materials in small electronics in consumer products.

Objective and intended effect/expected impact	Implementation	Feasibility and evidence
Significant amounts of small electronics are included in consumer products. A common feature of much of this small electronics is that it is integrated into textiles, toys, sporting goods and leisure equipment such as sneakers, which makes sorting difficult and is therefore less likely to be recycled than other EE waste. A ban on or excise duty on the use of critical raw materials for non-essential consumer products could minimise the proportion of CRM used for this purpose, and thus improve the security of CRM supply for high-tech applications.	Ban products with unnecessary electronic components including textiles with light, sensor, and microchips. Alternative an additional tax on such products that limit consumption or information campaign that raises public awareness about negative CRM-implications these products.	No national or regional initatives has so far been identifed.

An increasing share of electronics are small and used in applications we traditionally do not associate with electronics. While we usually think of electronics as computers, phones and TV sets – electronic components are now found in toasters, hairdryers, footballs, training jerseys and shoes.

The diversification of applications goes on. In a brand-new electric vehicle, one main neodymium motor is 1 kilogram. Still, there are tens, upwards of a hundred tiny motors: window heists, windscreen wipers, seat adjusters, air fans, mirror adjusters, etc. While removing the large piece of the engine is straightforward, picking out all the tiny bits and pieces is difficult, time-consuming, and impossible based on the current value of the metal in pieces.

While efficiency is crucial for the car's engine, it might not be equally important to have the highest efficiency in the motor that adapts the mirrors. Indeed, in many of these applications, less efficient ferritic or alnico-type magnets may replace efficient neodymium. While the use of these strategic metals gets diversified, it is also possible to consider diversification in regulations. Promoting efficiency in EV engines does not necessarily conflict with restricting the use of the same metals for these smaller applications.

While large WEEEs, such as computers, televisions, refrigerators, and washing machines, generally have a high collection rate, smaller appliances, such as toys and sports equipment, have a significantly lower collection rate – possibly as low as 10%.[90] For even smaller components,

90. Nowakowski, P. et al. Collecting Small-Waste Electrical and Electronic Equipment in Poland—How Can Containers Help in Disposal of E-Waste by Individuals? Sustainability 2021.

such as sensors and diodes embedded in larger units, the collection rate is likely even lower.[91] The largest loss is probably seen in these smaller, built-in components where the product itself is not considered WEEE.

Tiny electronic components in consumer products tend to end up in waste fractions and eventually be incinerated, which is an essential source for CRMs in incineration ash. Even if gold is not a CRM, an average content of 1-2 ppm in MSW incineration ash indicates a significant amount of small electronics. The content of 0.2-0.7% of copper has several origins, but small electronics will also contribute significantly here.

It is assumed that substitution of CRMs with less efficient elements could be a more sensible way to avoid these losses than both improved sorting and ash processing. For many products or product groups, a regular ban or other strong regulations should be considered.

Small household (SHA) and consumer electronics have often been mentioned for sharing and re-use schemes to reduce consumption. However, practical tests have shown that second-hand SHA have a minimal direct re-use potential, with a somewhat better potential if handled with proper testing and repair protocols.[92] While sharing schemes might have many positive aspects, there might be other paths to avoid the consumption and loss of CRMs.

The most strategic element, neodymium, is mainly known for its use as a magnet. However, it is also used in several magnesium alloys in electronics and lead-free solders.[93] Indeed, when neodymium is found in 500-700 ppm in waste printed circuit boards, one of the main contributors is the solder alloys.[94] Developing other solders with sufficient wettability and corrosion resistance should be possible without neodymium.

Toys are one of the fastest-growing sectors, both in terms of the overall tonnage of waste and the prevalence of electronic components. According to the WEEE collection schemes,[95] toys are a growing sector of concern due to the possibility of achieving collection rates. With toys rather often having a short lifespan, this sector might be targeted for substituting elements or restricting the use of electronics altogether.

Clothes and other textiles with electronics added, weaved or printed into and onto them have exploded in use the last two years.[96] While the E-textile industry argue sensibly for the use of sensors for medical reasons etc, the volume of the products is superficial and with limited essential use. Quite common is the use of silver or silver compounds and copper. For sensors, gallium-indium-alloys are used while tungsten is used for signalling systems. Also gold, nickel, high purity manganese and molybdenum is used.[97] Recycling of these textiles are double complicated, as the fine threads and print is not possible to recycle at all, while it also reduces the recyclability of the textile fibres. It is fair to say that this is a segment ready to be better regulated.

The Nordic countries have for many years had well established and rather well functioning collection systems for WEEE, despite the many exceptions and holes in the system that currently exist. Producers and importers of EE-products pay a high tax on their products to subsidize

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91. Chancerel, P. et al. Recycling-oriented characterization of small waste electrical and electronic equipment. Waste Management 2009.
92. Bovea, M. et al. Potential reuse of small household waste electrical and electronic equipment: Methodology and case study. Waste Management 2016.
93. Xia, Z. et al. Effect of Rare Earth Element Additions on the Microstructure and Mechanical Properties of Tin-Silver-Bismuth Solder. Journal of Electronic Materials 2002.
94. Bhavan, J. Identification and recovery of rare earth elements from electronic waste: Material characterization and recovery strategies. Materials Today 2023.
95. https://weee-forum.org/ws_news/invisible-e-waste-almost-10-billion-in-essential-raw-materials-recoverable-in-worlds-annual-mountain-of-electronic-toys-cables-vapes-more/
96. Meena, J. et al 2023. Electronic textiles: New age of wearable technology for healthcare and fitness solutions. Materials Today Bio.
97. Du, K. et al 2022. Electronic textiles for energy, sensing, and communication. IScience.

collection and treatment of equipment, but they observe a lot of free riders that legally or not avoid the obligations and put on market EE-equipment without paying for it. This include a lot of products where the electronics are built into larger equipment, or is not generally considered EEE, such as foot file or a shaver. In Norway, there is a general amnesty in regulations for EE-component smaller than 1 gram, as well as several other exceptions. Based on the requirements of CRMA, it is probably relevant to revisit the current regulation, and evaluate if exceptions still are legitimate, and if the number of free riders are too high for the system to develop properly.

Potential for substitution/waste reduction of critical raw materials

The quantity of CRMs used in small electronic components appears to be rapidly increasing, driven by the growing number of units and the overall material volume. These include gallium in diodes, neodymium in micro motors, and copper in micro-PCBs. However, due to insufficient and inconsistent data, it is not currently possible to provide accurate estimates.

Barriers

The electronics industry demonstrates remarkable skill and efficiency in downsizing components, reducing the use of expensive materials and quickly adapting or innovating designs. However, this rapid pace of change provides several challenges for the sorting and recycling processes, particularly in identifying and isolating smaller components. The smaller the components, the greater the challenge.

Manual handling of small electronic components during recycling is neither cost-effective compared to the production of new components nor proportional to the value of the metals recovered. Reliance on metal value cannot optimise recycling alone, additional measures are necessary.

Possible means of actions/instruments

Evaluate current WEEE-regulation regarding exception for EE-components less than 1 gram.

Evaluate current WEEE-regulation regarding relevance of all exception.

More research is needed to quantify tonnage represented by this sector, as well better understand the development trends and possible innovative identification and sorting technologies that can bring down the recycling cost per ton.

Information campaigns towards the public promoting sorting and delivery of even small WEEE components.

Support R&D programs towards substitution with non-CRM elements.

Ban the sales of textiles with electronics, light diodes etc, with exception of certain medical uses and defence/security applications.

Ban the sale of shoes with light diodes, sensors etc. Shoes are better without.

Ban the use of chips and sensors in footballs, golf balls and similar sports equipment. Balls can be found without electronic tracers.

Ban the use of electronics in napkins to monitor humidity. A soiled napkin can be smelled.

Ban the use of electronics in coffee mugs to monitor temperature. Humans are able to sense heat.

Ban the use of electronics and Wi-Fi in cat litter boxes. Cats can do their business without Wi-Fi.

Replace electronically printed starting numbers with basic QR codes.

Ban use of electronics in furniture outside of the hospital sector. Beds and chairs can do without Wi-Fi.

Ban the use of electronics in birthday cards and similar one-time products. This will also reduce fires in the paper recycling value chain.

Ban the use of electronics as purchase promotors for comic books and other items marketed to children.

Propose a negotiated agreement with the EE-sector where all smaller items with low collection rate (i.e. headphones, ear plugs, remote controls, sim cards etc) where each item is added a deposit which is refunded with a double voucher from the shop (customer pay €10 deposit, gets €20 voucher from shop when returned). Net sales from abroad are added same deposit as a tax.

Socio-economic impact

Many small electronic appliances and components greatly benefit society and humanity, so restrictions and limitations should be implemented carefully. However, the loss of CRMs from small electronics is probably substantial, so the sector must be addressed.
It is impossible to foresee a recycling solution with currently available technologies that will be profitable from the value of recovered metals.

2.1.9 Increase the number of CRMs and overall extraction efficiency from ore mined in the Nordic region.

Table 2.9 Summary of the measure: Increase the number of CRMs and overall extraction efficiency from ore mined in the Nordic region.

Objective and intended effect/expected impact	Implementation	Feasibility and evidence
Critical raw materials such as copper, cobalt and nickel are included as by-products that are often not extracted from ore processed in the Nordic region. More advanced beneficiation techniques have the potential to extract more of these CRMs from beneficiation processes, thereby minimizing the waste materials that subsequently need to be landfilled.	Restructuring taxation of Nordic mining industry to insentivice increased extraction of CRM-byproducts from processed ore.	No national or regional initatives has so far been identifed.

The Nordic countries comprise the most important mining region in Europe,[98] with an annual extraction of 150 million tonnes of metal ore – and the subsequent landfilling of 100 million tonnes of tailings. The industry has a few large companies but also a rich and diverse flora of smaller operations, spread around Norway, Sweden and Finland.[99] Three small operations are

98. Wittenberg, A. Critical Raw Material Resource Potentials in Europe. Materials Proceedings 2023.
99. Feltrin, L. et al 2024. Information Management and Classification of Secondary Resources and their Critical Raw Material Potential in the Nordic Countries. Nordic Innovation.

active in Iceland and Greenland. The value of the minerals produced in Fennoscandia are substantial for their host countries. The importance of the supply of CRMs such as copper and nickel for Europe should be noticed. However, these industries also generate and landfill enormous amounts of wastes – the tailings. The tailings contain more CRMs than all other waste streams that are produced in the Nordics. The annual production of mineral waste from Nordic mining operations can however be reduced through more efficient use of the mineral ores.

Out of all waste fractions generated in the Nordic regions, the tailings represent over 50% of the tonnage for 28 CRMs. Some of these volumes are at a level where commercial production should be possible.

Table 2.10 Some of the CRMs lost in tailings – every year. Source: Bergfald Miljørådgivere.

CRM	Tonnes
Praesodymium/neodymium	2998
Cobalt	10880
Copper	61031
Nickel	40066

Whether policies towards losing fewer CRMs to the tailings landfills are defined as industrial process optimisation, improved resource management, circular economy, or CRM supply security is of less importance, the main thing is that CRMs currently lost to the tailings should be extracted and supplied to downstream industries instead.

There are several very good stories to observe and support.

In Sweden, LKAB has been engaged for many years in developing processing steps to extract and refine the content of phosphorous and Rare Earth elements present in their magnetite tailings. While the presence of rare earth minerals in the ore has been recognised for a long time, LKAB's decision to prioritise their utilisation has been a recent development. Once mobilised, however, the scale and scope of LKAB's efforts have surpassed those of the other mining companies combined. Numerous different work packages and projects have been initiated to prepare for substantial investments into the value chain, from anything from changes to ore priorities to ore processing[100] in several steps[101] and separation in a newly built plant in Norway.[102]

Another resource is vanadium, where a handful of Nordic mines landfill more than the whole European consumption of the strategic metal – at a point in time where 100% of the supply of vanadium is from BRICS countries.

There are, however, less positive examples. The Norwegian nepheline mine at Stjernøya, for instance, produced a phosphorous by-product known as "Altagro", which was supplied to farmers for many years. Despite this product being approved for organic farming and extracted from waste, it was challenging to market due to its gradual phosphorous release and its inability to

100. Wanhainen, C. et al. Rare earth mineralogy in tailings from Kiirunavaara iron ore, northern Sweden: Implications for mineral processing. Minerals and Metallurgical Processing 2017.
101. https://lkab.com/en/what-we-do/our-transformation/critical-minerals/circular-and-fossil-free/
102. https://www.highnorthnews.com/en/norwegian-swedish-cooperation-rare-earth-metals-marks-beginning-something-new-europe

lower soil pH. Norwegian farmers preferred phosphorous imported from Russia, which had a lower pH. As a result, the mine at Stjernøya closed its by-product operations and began disposing of the by-product into the sea instead.

A closer examination of the Nordic mineral industry reveals numerous similar cases – both positive and less favourable. These examples underline the need for both regulations and incentives to achieve appropriate resource management.

Globally, the extraction of minor CRMs from base metal mining is much more common than in the Nordic. All the global production of gallium, germanium, indium and hafnium comes from small extraction units plugged into large processing plants for bauxite, zinc and zirconium. The important REE sector has been possible to grow due to the Chinese starting to process a by-product from their low-grade magnetite mine in Inner Mongolia, and that is what LKAB is proposing to do in Sweden as well. The by-products from the Chinese iron mine are still the largest REE mine in the world, twice the size of number two.

While base metals such as iron and copper are mature markets with many stakeholders, and the possibility over establishing protected investments through secured offtake agreements, many of the CRM niches are very vulnerable and without established protection mechanisms. Indeed, any investment made by a mining or mineral processing company towards new units for CRM extraction should receive governmental protection. This can be as substantial CAPEX grants, soft loans, price/offtake guarantees or other agreed mechanisms that protect an investment.

Potential for substitution/waste reduction of critical raw materials

As copper, nickel, and cobalt are all considered CRMs, one of the most resource-efficient ways to increase CRM supply is to incentivise mining companies to improve their extraction efficiency. Whether the operations are based on gravimetry, flotation, heap leaching or whatever concentration technology is proven, there are options such as increased processing time, more steps, more water, secondary (or tertiary) crushing and additional steps. For instance, the 100 million tonnes of tailings landfilled in the Nordics contain 10,000 tonnes of cobalt. In comparison, the largest dedicated cobalt mine in the world, in DR Congo, produces 23,000 tonnes per year. Through more efficient ore dressing a significant part of this cobalt can be recovered.

Sweden has been at the forefront of systematically mapping CRM resources in abandoned mine tailings facilities,[103] with outstanding reports from the Bergslagen region.[104][105] And Sweden, mainly represented by SGU, has found and mapped billions of tonnes of materials with millions of tonnes of CRMs. However, while government funding finds and maps the elements, more is needed when recovery is established. Many programs have been initiated to reprocess old mine tailings, such as Grängesberg, but very few have succeeded. Unfortunately, tailings have been exposed for decades, becoming much more difficult to process or reprocess. This is especially true for tailings exposed to several tens of freezing/thawing every winter for decades; the surface chemistry changes so much that traditional mineral processing technologies become less efficient – if applicable.

Hence, a tailings deposit should not be considered a bank of elements. Unless new and unidentified technologies come to the market, tailings that have lasted too long should be regarded as lost. The obvious conclusion is to incentivise the mining industry to extract more from the feedstock, passing their plants and leaving less for the tailings.

103. SGU 2023. Hållbar utvinning och återvinning av metaller och mineral från sekundära resurser. Rapportering av regeringsuppdrag
104. SGU 2024. Characterisation of mining waste in central and western Bergslagen, Sweden
105. SGU 2022. Characterisation of mining waste in central and southern Bergslagen, Sweden.

The Swedish Government concluded last year that Sweden had comparative advantages in supplying CRMs as by-products from the processing of commodity minerals.[106] While Sweden probably has the largest such advantages, there are interesting opportunities in Norway and Finland[107] as well.

Barriers

The largest barrier is industry conservancy. A gold mine will produce gold, and often the ore has not been analysed for other valuable minerals. The industry is also often hesitant when it comes to testing and developing new process steps that can increase extraction efficiency. This barrier can be lowered by information campaigns towards the industry and dedicated courses in the education of geologists, mineralogists and mining engineers.

Permitting also represents a barrier. Receiving a permit to operate a mineral resource in the Nordic countries takes many years and costs millions of euros. Having obtained an initial operating permit, a mining operation will often hesitate to apply for additional extraction options that will require much time and money.

The sequential processing of minerals to extract different minerals is complex. It will involve a development and test phase, which can be quite costly and require expertise in mineral processing. Adding additional extraction steps to a mining operation increases the complexity and risks of the mining operation that may also lead to avoidance of such an endeavour.

Knowledge gaps can also be surprisingly large. Mines with billions in revenue sometimes operate without a detailed overview of the elements passing through their processing plants.

Possible means of actions/instruments

Restructure the taxation. Remove all income taxes and royalty duties from mining operations in the Nordic, and tax the companies according to the metals value of the CRM they waste.[108] That will double the value of any tonne of extra copper, REE or lithium that is extracted from what is currently wasted.

Support R&D into new extraction and beneficiation technologies by dedicated programs.

Provide a new financing model where government royalty loans are given to mining companies to improve extraction rates or establish new process steps for CRMs. Loans should cover 100% of CAPEX of investments and be fully paid back as a fixed royalty payment per ton produced.

Remove political restrictions on extraction of uranium and thorium by-products, as such extraction may also be unlocking minor CRMs.

Socio-economic impact

The metal's value of CRMs[109] annually landfilled in the Nordic countries is € 14 billion, including a gross value of € 2 billion for lost copper, cobalt, and nickel. Assuming a net smelter value of 65% of the metal's value and an extraction improvement in line with the CRMA recycling goal of 25% represents industrial value creation of about € 2,3 billion. These are realistic figures for a new industry that can develop in the Nordic region and will increase CRM security without losing nature or making more waste.

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106. Myndigheten för tillväxtpolitiska utvärderingar och analyser 2023. En resurseffektiv och konkurrenskraftig metall- og mineralnäring.
107. Karlsson, T. et al. Potential of Critical Raw Materials in Closed Finnish Mine Waste Sites: A Preliminary Review. Proceedings of ICARD 2024.
108. Such a taxation will need to have some exceptions/clarifications for elements such as silicon and aluminum.
109. Excluding aluminum, silicon and magnesium.

2.2 Measures for re-use and repair

The following sub-chapters describe possible measures for the re-use of CRM-containing products and components.

2.2.1 Assess the possibility of reusing optical cables with CRM content

Table 2.11 Summary of the measure: Assess the possibility of reusing optical cables with CRM content.

Objective and intended effect/expected impact	Implementation	Feasibility and evidence
Reusing germanium-containing optical cables could reduce the need for germanium for this purpose. Optical cables can also contain other CRMs, such as REE.	A system for collection and preparation of end-of-life optical cables for re-use should be considered.	No national or regional initatives has so far been identifed.

Optical cables do not represent large tonnages of waste, but like all other cables, they are a widespread bank of material dispersed in society. Optical cables are based on many different technologies, but most are based on high-purity silicon glasses doped with some CRMs. For communication cables, germanium is the prevailing CRM, and the cables are the most critical use for germanium. However, many niches also exist, such as cables doped with holmium or ytterbium.

Optical cables are almost permanent in their quality except for mechanical breakage and fires. Degradation by time is minimal. Hence, these components are very suited for direct re-use. That said, both possible long-term re-use and later recycling of the cables need to be considered already in the design phase to avoid complications and costs.[110]

The leading supplier of high-purity germanium to Europe has long been Russia, which is based on extraction from coal ash and refining in their Krasnoyarsk plant. There is germanium processing capacity in Europe, but access to feedstock is needed. Indeed, as these supply lines have been negatively distorted over[111] the last few years, even the production of the cables has been, to a degree, moved to other BRICS countries.

While high-purity silica is the primary material in most cables, there are also commonly CRM additives made of flour and zirconium,

While it can be tempting to consider substituting small and supply-sensitive materials such as germanium, this will have negative consequences for the cable performance. Germanium has significant features for the signal quality in the cables, so a combination of increased extraction from industrial wastes and collection and re-use/recycling of cables would probably best solve the supply issues of this CRM.

110. Wright, E et al . Improving recyclability by design: a case study of fibre optic cable. Resources, Conservation and Recycling 2005.
111. BRICS include Brasil, Russia, India, China and South-Africa

Optical cables have been in use for several years already. At the same time, technological development has spurred on fast – it is fair to assume that a substantial tonnage is presently in society but not in use. In Sweden, it has previously been calculated that billions of SEK worth of copper cable are idle in the ground, representing huge urban mining potential for the future. It is fair to assume that optical cables are similarly left – and describe this possible future resource.

Optical cables have entered the automotive sector in the last decades, with the control of all kinds of sensors, cameras, and infotainment screens. The composition and doping of these cables are slightly different from the cables typically used in buildings, but it is still highly relevant materials.

Large-capacity cables are used for long distances, such as in subsea cables connecting continents. In recent years, it has been observed that some of these cables have been deliberately cut or sabotaged. So far, it seems that it has been possible to repair these, but it might be in the future that it makes more sense to bring the cable onshore[112] for repair or use in other applications, while cable less easy to sabotage is installed.

Besides communication, these laser fibres, with their CRM doping, are also used for medical lasers in eye surgery and diagnostics,[113] and in many research and industrial applications. Only sometimes in many grams or centimetres per unit, but necessary and impossible to substitute. As there is a substantial production of these specialised cables in the Nordic countries,[114] it might be possible to develop some industrial loops, adding to Nordic competitiveness. Some of the Nordic producers are already promoting reusable and re-used optical fibres, amongst others, for medical applications.

Potential for substitution/waste reduction of critical raw materials

The main challenge to improved circularity and waste reduction for optical cables in general and their germanium content, particularly, is the proper dismantling and collection. If collected, it is likely to be re-used. All scraps, cuttings, off-specs, breakages, can be recycled to a 99% efficiency.[115] Indeed, if the collection issue is resolved or improved, it is possible to achieve close to 100% circularity of disused cables. It is however necessary to stress that the volume of cables in total is still growing at a steady pace, so more virgin material will be needed for many years to come, as even 100% re-use & recycling of cables will not cover the market needs. However, close to zero loss of the CRMs applied in optical cables is possible.

Barriers

Cables are installed according to the needed length, size, etc, so all returned and sorted cables will be on an "off-spec" level compared to virgin cables.

The labour cost of careful removal and winding of used cables, classification, testing, etc, will be significant but comparable to the value of the cable.

The competence of the demolishing and waste-sorting labour force may differ from that of the fibre-installing electricians.

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112. https://www.fibre-systems.com/feature/submarine-salvage-second-life-old-cables
113. Knudsen, B. et al. Durability of reusable holmium:YAG laser fibers: a multicenter study. J. Urol 2011.
114. www.nlight.net/locations
115. Chen, W. et al 2017. Recovery of germanium from waste Optical Fibers by hydrometallurgical method. Journal of Environmental Chemical Engineering.

Possible means of actions/instruments

Mandatory marking of all optical cables with content and other parameters relevant for reuse.

Mandatory removal and return of disused cables when installing new cables.

Mandatory removal and return of all cables when demolishing or renovating all buildings.

Map the prevalence of installed and unused cables that could easily be dismantled for re-use or recycling.

Mandate the automotive dismantler to remove all optical cables before shredding.

Socio-economic impact

The careful removal of disused cables during the renovation of buildings and dismantling of cars will require some labour costs. Considering the overall longevity of the cables (if adequately handled) and the cost of such cables, these costs should be comparable.

Other variants of the measure

Public sector building authorities (schools, hospitals, and nursing homes) may take on voluntary requirements in their renovation procedures.

2.2.2 Reusing magnets in electric motors, pumps and "dynamos"

Table 2.12 Summary of the measure: Reusing magnets in electric motors, pumps and "dynamos".

Objective and intended effect/expected impact	Implementation	Feasibility and evidence
Reusing electric motors in pumps and other electrical components, or the magnets they contain, could reduce the need for new magnetic metals of the same type. However, material fatigue will limit the reuse possibilities for certain components. Proper testing of the components is therefore important before re-use. The scheme should perhaps be limited to manufacturers only recalling their own products.	Encourage standardization of magnet chemical composition, design form and size that supports reuse of magnets in new generations of products. Support magnet reuse schemes in industry	Some legislation regarding these issues are expected to follow from CRMA

Permanent magnets are needed as small but essential components in the green transition with renewable energy, electrification, digitalisation, and defence. While strong in effect, most of the currently used permanent magnets are rather sensible, prone to oxidation and brittle. However, if protected efficiently and handled with care, they can also be used for a long time and potentially re-used many times.[116]

116. Li, Z. et al. Direct reuse strategies of rare earth permanent magnets for PM electrical machines – an overview study? Eur. Phys. J. Appl. Phys. 2019.

Due to its high cost and strained supply line, the direct re-use of magnets is probably more extensive than we currently assume, as it is done without reporting. Statistics is often a challenge when products are re-used. In contrast to recycling plants, where tonnes of materials are processed with substantial energy and chemicals in large CAPEX plants, direct re-use in its simplest form is manual labour, removing one component from one place and installing it in another. Although it might be more complicated in many magnet applications, direct re-use that avoids involving the long and complex processing routes of magnets has the most significant environmental potential.

The strongest and most energy-dense/energy-efficient permanent magnets are based on neodymium (NIB) technologies. These magnets are however unfortunately rather sensitive to high and low temperatures and most mechanical impacts. The materials are brittle, and minimal impact is needed to reduce or destroy its magnetism. For several applications, especially defence, less efficient but more robust permanent magnets are therefore used. Substantial defence gains can be achieved if more robust neodymium magnets are developed. While firstly used in defence products, these improved magnets will also quickly come to the civilian market.

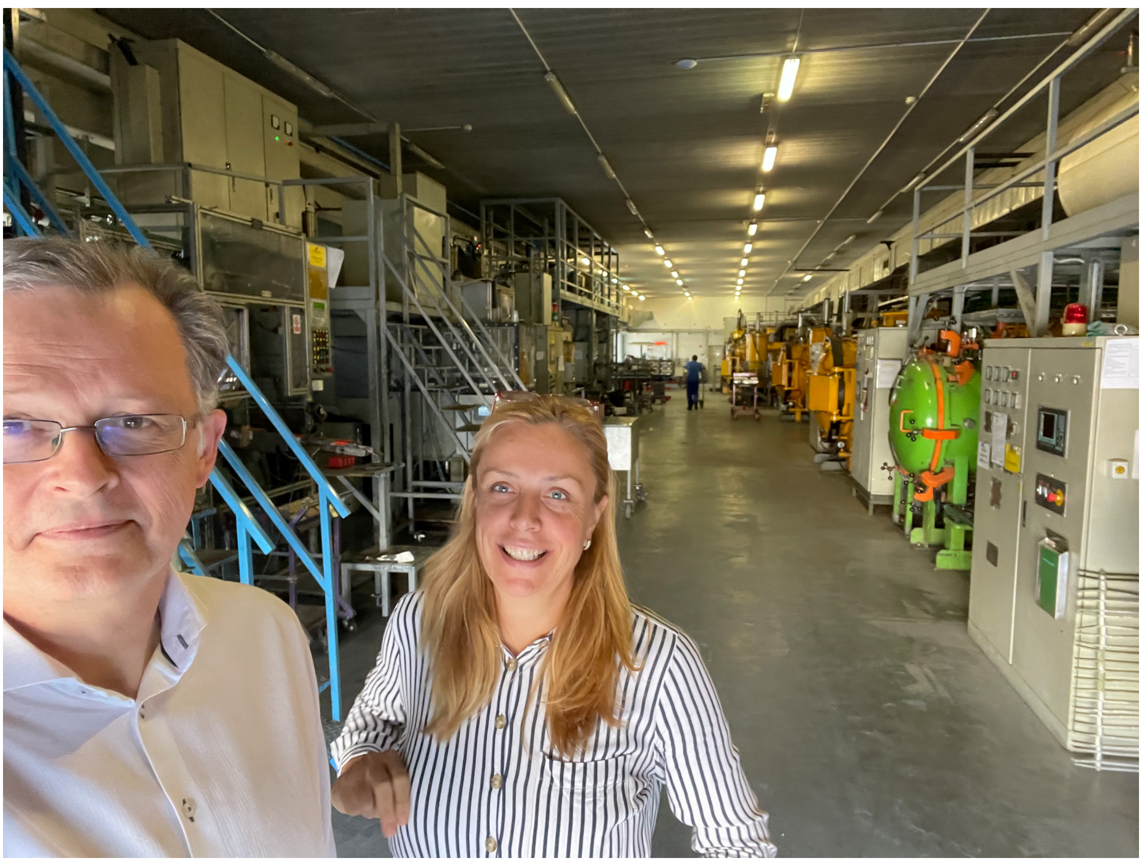

Figure 2.6 Very few permanent magnets are produced in Europe, as prices of magnets are low. To the left is an exception, as are the vacuum PM magnetising and sintering furnaces in Ljubljana. Photo: Bergfald Miljørådgivere.

While most of the research into advanced magnets takes place in China rather than in Western countries, Europe and Nordic countries observe the results only much later on. The new chemistry is revealed when scrap magnets area analysed from equipment made in China. For instance, neodymium magnets are observed with the addition of holmium[117] or gallium.[118] Such addition is rarely mentioned in scientific literature before its introduction to the market but is found in scrap magnets – after which articles start appearing. As there is no primary production of either holmium or gallium in the Western world, the Nordic countries are forced to re-use Chinese magnets if similar qualities are to be obtained.

If the magnet is extracted without being broken, it can be measured and classified and possibly used again.[119] Re-use understood as mechanical dismantling and retrofitting into a new application is proven to be efficient for larger magnets. Some challenges arise, such as releasing the adhesives and having an efficient coating.[120]

In many cases, it seems beneficial to demagnetise the sorted unit and then remagnetise it before installation and re-use. A proper post-consumer demagnetising and remagnetising setup for different magnet types has yet to be industrialised, but lab and pilot tests do exist.[121] Similar modelling shows that removing a magnet from one application to another will only reduce performance by 0.11%.[122]

If magnets are broken, or the alloys are off-spec, powder recycling can also be considered preparation for re-use as it is distinct from chemical recycling. Although not being re-use according to the strict definition of the Waste Framework Directive of EU, this process is commonly referred to as reuse by the industry to separate it from chemical recycling. One variant of powder recycling can involve the use of hydrogen gas,[123] which will penetrate the magnet, demagnetise it and separate the magnet alloy material from the coating. The magnet alloy powder can, if necessary, be blended with virgin materials to achieve the correct alloy composition before being magnetised and sintered as if it were an all-virgin product.

It is similarly possible to dissolve such broken or off-spec magnets in ethanol, hydrolyse the neodymium and then recentre the powder into a new magnet.[124]

Figure 2.7 shows an overview of processes for re-use of magnets that gradually become recycling operations.

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117. Couto, C. et al. On the pre-treatment for recycling spent NdFeB permanent magnets: from disassembling, characterisation to de-coating. Sustainable Materials and Technologies 2024.
118. Huang, Q. et al. The influence of Gallium doping on the magnetic performance and microstructure of Nd-Fe-B sintered magnets. Journal of Magnetism and Magntic Materials 2022.
119. Sagna, A. et al. Non destructive control of permanent magnet rotors in a perspective of electric motor circularity. Procedia CIRP 122, 2024.
120. Hogberg. S. et al. Direct Reuse of Rare Earth Permanent Magnets - Coating Integrity. IEEE Transactions on Magnetics 2017.
121. Kim, B. et al. A study on demagnetization heat treatment of waste neodymium iron boron (NdFeB) magnets by using computer simulation. Peer J Materials Science 2023.
122. Pakstys, S. et al. Effects of Recycled Permanent Magnets on Electric Machine and Hybrid Electric Vehicle Performances. ASME 2023.
123. Burkhardt, C. et al. An overview of Hydrogen assisted (Direct) recycling of Rare earth permanent magnets. Journal of Magnetism and Magnetic Materials 2023.
124. Philippot, G. et al. Pulverization of Permanent Magnets by Solvothermal Chemistry for Direct Recycling. ACS Sustainable Resource Management 2024.

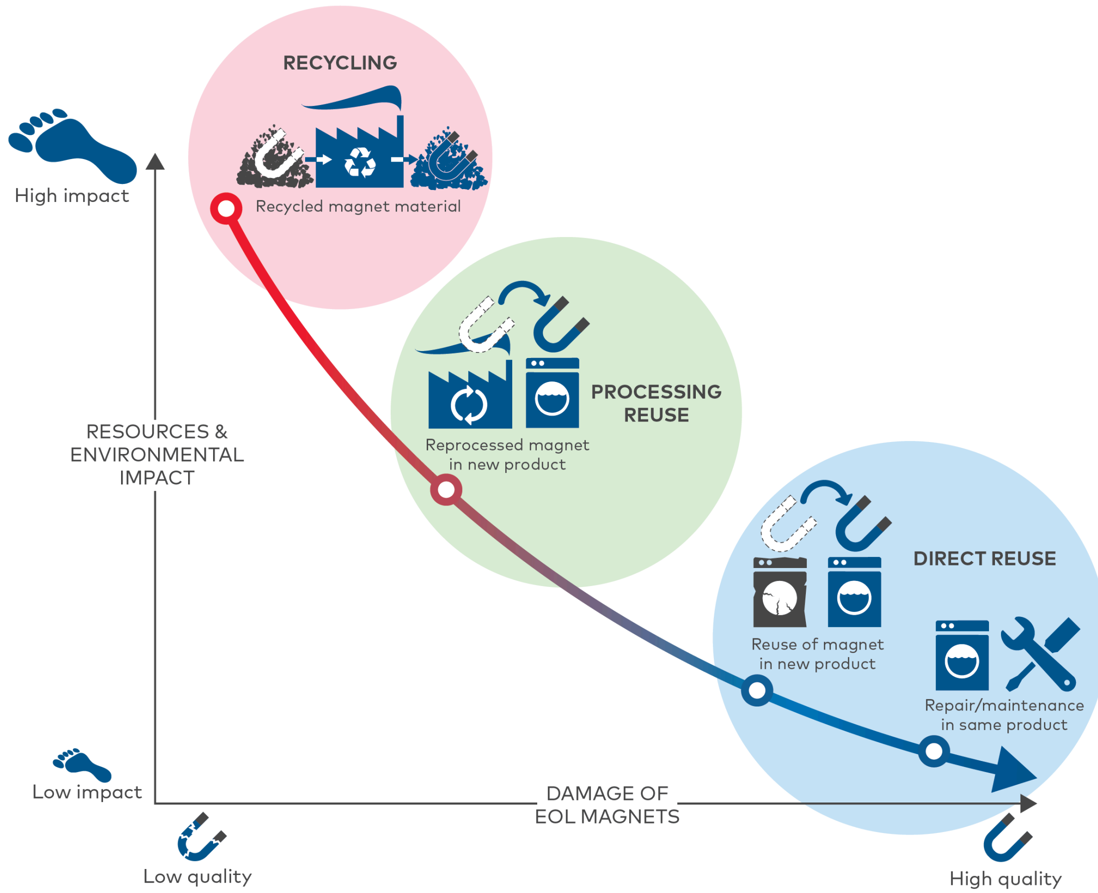

Figure 2.7 Powder recycling can be seen as a blended technique between re-use and recycling processes. Compared to chemical recycling, powder recycling requires less input of energy and chemicals, have a lower environmental footprint and is an available technique for repurposing magnets too damaged for direct re-use. Illustration Bergfald Miljørådgivere.

Several large Nordic companies have understood the importance of these small magnets to their operations as well as the political and environmental footprint they represent. Some companies have set forth ambitious plans, such as Vattenfall that are preparing for 100% circularity of the magnets used in their power production, with a combination of direct re-use and recycling.

The Danish company Grundfos has already, for many years, been a pioneer in reusing permanent magnets. Grundfos is a leading pump technology company responsible for millions of units operating worldwide. For some time, the company has operated a refurbishment unit where used pumps are taken back, overhauled, and sent out again.[125] Pumps that are worn too much are dismantled, and if key components such as the magnet can be re-used, the magnets are checked and used in a new product. If the component is flawed – it is directly sorted for recycling, effectively creating a precise sorting path.

125. www.grundfos.com/solutions/learn/research-and-insights/hvac-oem-take-back-programme-circularity-by-recovering-pumps

Figure 2.8 Functioning RE magnets in broken pumps can be re-used in new products. Photo: AdobeStock.

However, while companies such as Vattenfall and Grundfos can establish circular business models for their products and magnets, it is more complex to do this on a societal level.

There are at least four challenges to address when working towards increased re-use of magnet structures.

Information gaps on composition. When companies such as Grundfos establish circular business models and take back their products, they know exactly which components they get and have a clear idea of what to do with them. It is rare if at all observed, that such takeback systems will take in the equipment from competitors. It cannot be expected that a producer of high-value equipment should be forced to install a used component from a competitor.

Small and hidden items. Most of the magnets used today are small, less than 10 grams, and often less than 1 grams. A typical example are electric vehicles, with one big magnet in the motor and around 70 small magnets spread all over the car. Finding and dismantling these small items and sorting, classifying, testing and sending them for re-use will be very costly.

Shapes are shifting. As designers are free to do whatever they like, models of all kinds of equipment change from year to year and sometimes even months to months. As part of that, a magnet used in an e-bike produced in January might not be re-used in the same model coming in June of any given year. This issue can be solved by limiting designer freedom and standardising some shapes and Gauss's strengths. The "Lego" model can also improve it, i.e. producing magnet building blocks in exact shapes that can fit into each other and build larger magnets from that. If so, these building blocks could be re-used into new shapes and forms, both smaller and larger. Such standardisation will make take-back programs much more financially attractive for producers of electric vehicles, pumps, and power tools.

Another challenge is differences in the magnet metallurgy. There are dozens of different magnet alloys used, partly for different applications but, unfortunately, also in direct competition. These alloys include CRM-based alloys such as NIB, AlNiCo and SmCo. As these different alloys have different features and need quite different processing, if direct re-use is not possible. There is a need to implement content labelling.[126] A typical label could, for example, state, “NIB 27-70-3” or “ANC 8-16-24”, indicating the magnet system and relative content between the main elements. Any labelling of these magnets will regardless have to comply with Article 28 and 29 in CRMA.

As the processing chain of making permanent magnets is so long and includes so many steps, many of the technologies the industry described as re-use although does not adhere to a strict interpretation of the definition in the Waste Framework Directive of EU. Sorted magnets will be demagnetised, electrolytically or thermally removed coating, crushed, reshaped, remagnetised, and sintered into a new product.[127] An overview of possible techniques used for re-using and recycling that show how these techniques gradually become blended is shown in figure 2.9.

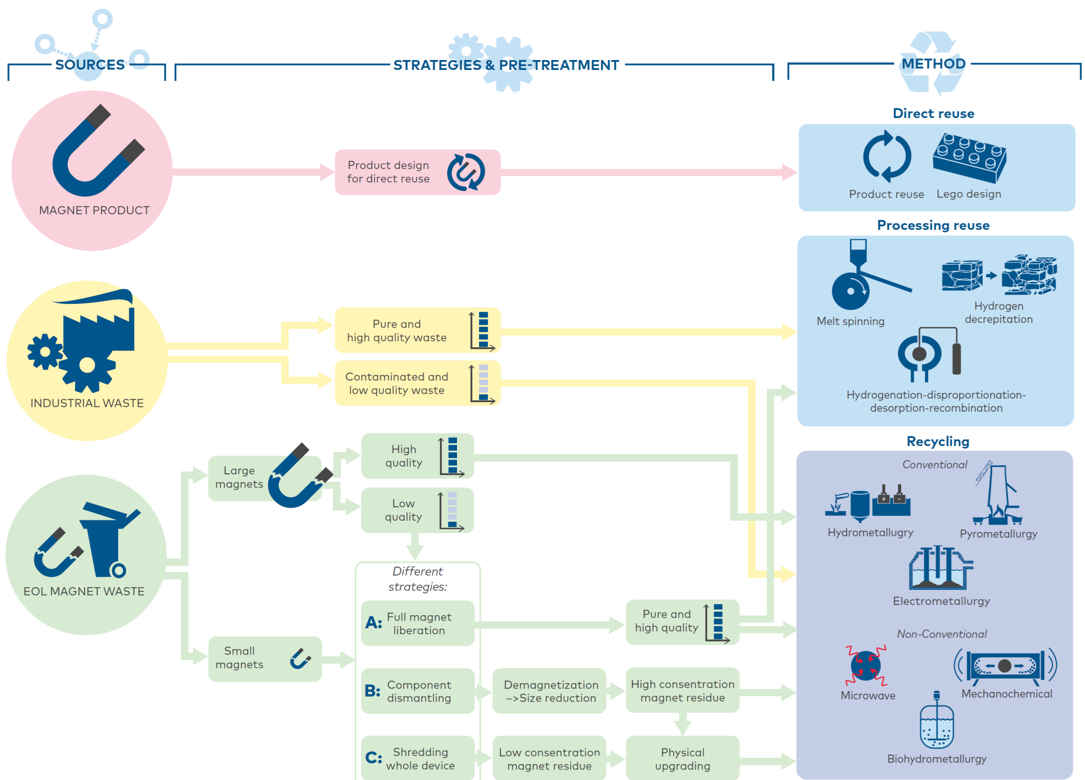

Figure 2.9 overview of possible techniques used for re-using and recycling magnets. Illustration Bergfald Miljørådgivere.

Potential for substitution/waste reduction of critical raw materials

If properly made and coated, a permanent magnet can almost perform according to its name – permanent. As a general rule, permanent magnets outlive their applications in automotive, pumps, fans, and computer applications. Establishing proper systems for removal, identification, quality control, protection and repair as a first line of re-use can reduce the need for replacement materials. It is important that these procedures are developed in accordance with Article 28 and 29 in CRMA. The second line of re-use/mechanical recycling will be demagnetization/ remagnetisation systems, while the third line will be decorating, crushing, and producing new

126. Rizos, V. et al. Developing a supply chain for recycled Rare Earth Permanent Magnets in the EU. Report 2022.
127. Cherkezova-Zheleva, Z. et al. Green and Sustainable Rare Earth Element Recycling and Reuse from End-of-Life Permanent Magnets. Metals 2024.

magnets. Magnet materials falling below quality norms in these three levels of re-use will need to go to chemical recycling.

While the electrification of society will require much more magnet metals than re-use and recycling can provide, these needs are at least eased when some of the current consumption can be avoided by re-use.

Barriers

By nature – magnets will stick to iron and steel infrastructure, so dismantling, sorting, storage, and transportation are complicated and costly.

Many magnets are very small, fractions of a gram and it is not possible to justify the manual labour cost needed to dismantle and handle them.

There has been a fast development of magnet technology, so both magnet alloys and their coating are according to producer specifications and not industry standards.

Some methods needed to dismantle and extract the magnets will break and/or demagnetise them.

Equipment manufacturers will usually not uphold their fabrication guarantee if components not delivered by themselves are used in repairs. This must either be forced upon them, or another type of guarantee must be created to keep consumer confidence for re-used components.

Possible means of actions/instruments

Establish standards for magnet type (alloy) and coating for mass-produced applications.

Establish eco-design requirements for an adhesive type that is possible to release without destroying the magnet.[128]

Introduce standard labelling of magnet type on all magnets more than 1 gram in accordance with Article 28 of CRMA.

Introduce a subsidy of 1 Euro for every REE postconsumer magnet re-used, independent of size of magnet.

Mandate picking of magnets from waste equipment such as automotive and WEEE before shredding.

Socio-economic impact

Direct re-use of permanent magnets will reduce the environmental footprint and increase raw material resilience.

The re-use value chain is inherently a manual operation, with identification, dismantling, testing, sorting and reinstalment. While it is conceivable that automation and robotisation may play a role in these operations in the future, state-of-the-art technology still needs to be there. Consequently, one of the significant socio-economic impacts will be employment.

Other variants of the measure

Increased re-use of magnets in less demanding applications is also an option, for example through programs where used EV motors are re-used in water pumps.

128. Upadhayay, P. et al. Applicability of Direct Reuse and Recycled Rare Earth Magnets in Electro-mobility. 7th International Conference on Renewable Energy Research and Applications (ICRERA 2018)

It is possible to mandate programs for take-back and re-use for producers of specific equipment, such as power tools, EVs, e-bikes, pumps, and AC.

Consider legal design requirements using "lego-composition" that allow more flexible retrofitting of used magnets in new applications.

2.2.3 Reusing CRM components in discarded EE products

Table 2.13 Summary of the measure: Reusing CRM components in discarded EE products.

Objective and intended effect/expected impact	Implementation	Feasibility and evidence
There is already an established market for still usable components stripped from end of life electronic products. This market can be further developed. CRM components such as magnets (REE), vibrating elements (W), capacitors (Ta) may be used in new products or as spare parts during repairs.	Support reuse of electronic components through tax incentives and collection schemes	No national or regional initatives has so far been identifed.

One important way to reduce CRM supply restraints is to ensure the equipment already in use is kept in operation for as long as possible by being maintained and repaired. When it in the end fails – then take out components that still can be re-used to repair other equipment. Re-use is one of the key strategic foundations for the Critical Raw Materials Act and one of the leading EU goals for extending the operational lifetime of electronic products in Europe.[129] Many positive trends on this topic however can already be further stimulated.

Since electronics where introduced, electronic equipment has been dismantled and components picked out for re-use. Still today, some components, such as HDDs, have a secondary market in the Nordic countries, while a broader range of components have a secondary life in many other countries.

As electronic components are costly equipment, reusing them has an economic potential. Estimates show that the global market for re-used electronic components is already at several billion Euros.

Globally, there are hundreds of large enterprises trading in used components from electronic products, reflecting the value of these components.[130] This second-hand component industry or activity is so far driven entirely by market forces, not legislation or incentives. Working with this market force and stimulating this further by introducing incentives might provide further growth.

It is possible to divide this market into at least two segments and two material flows. It is the direct re-use of the whole product, dismantling and using components to repair other products, which are two distinct market segments. Companies and individuals can deliver both products and components.

129. www.elektro-ade.at/wp-content/uploads/2017/07/EU-Parlament-will-l%C3%A4ngere-Nutzung-von-elektronischen-Ger%C3%A4ten-durchsetzen-ZDNet.de_.pdf
130. https://electronicparts-outlet.com/en/

One such example is the online platforms for secondary products. The Norwegian market leader is Finn.no,[131] like the Swedish Blocket. On these platforms, all kinds of items are sold, mostly from person to person, rarely with any guarantee or insurance. Despite all issues and shortfalls, these markets are thriving. A snapshot at Finn.no on December 1st showed 13,022 advertisements for selling second-hand mobile phones or phone components. Almost all of these are person-to-person transactions.

Similarly, the same snapshot showed 8,870 ads for laptops, 3,694 for gaming computers and 4,450 for TVs. All included were more than 200,000 advertisements for secondary electronic equipment simultaneously in Norway. Suppose a similar snapshot was performed for the other Nordic sales platforms. In that case, it is fair to expect that for the Nordic region as a whole, at any point in time, about 1 million pieces of second-hand electronic equipment or components are up for sale. Re-using electronic equipment is no longer a resource strategy; it is a solid and sizeable economic activity. In addition, several market players, such as Blocket, Teleoutlet, or OneCall, should be mentioned for actively promoting and building up the market segment for "nybegagnat elektronik"[132] – slightly used electronic products and "Nesten ny"[133] – almost new mobile. These private enterprises are doing the re-use promotion for all of us – without any regulation or incentive.

The thriving one million pieces of second-hand electronics market also shows that broad parts of the population accept buying second-hand products and components, and broad parts of the population find selling those products worthwhile. And indeed, many accept buying repaired equipment.

Several factors have been behind this waste prevention success: the existence and constant development of the trading platform, the perceived understanding by the populous of the items having residual value, the rising cost of living, the reduced purchasing power and the high prices of new equipment. Buying and selling used equipment and components make sense for most people. It might also be that the population, in general, has a preconception where they are accepting that a second-hand mobile for € 500 will fail after a couple of years (because all former mobiles have done so) in contrast to a used car for € 10,000 that is expected to last longer.

All the factors that have made these platforms efficient for marketing used equipment must also be deeply considered for the components and repair sectors. While sales of components will hardly reach the same broad population as the equipment, the acceptance of buying "new" equipment based on "old" components may be achievable and possibly is, to a large degree, already.

While all of these issues are real, the success of platforms such as finn.no and blocket.se show that these issues are internalised and quantified in a market system where a sufficient number of buyers and sellers can internalise and quantify these concerns into an issue of equipment price.

In Sweden, consumer electronics producer Electrolux and recycling operator Stena have observed these market trends for many years and are trying to adapt. Together, they are developing vacuum cleaners based on recycled components and have taken the experience of this second circle back into their design criteria. We assume less glue has been one of the parameters set for recyclability. For several decades, Siemens computers and Tomra recycling machines have developed similar circularity and "prepared for takeback" production parameters.

131. https://www.finn.no/bap/forsale/search.html?category=0.93
132. https://www.blocket.se/nybegagnat?utm_source=blocket&utm_medium=web&utm_campaign=fp-icon
133. https://onecall.no/kampanjer/nestenny

Still, despite these apparent market successes and industry adaptions, there are some strange effects regarding public perceptions, and one of the most obvious is the difference in attitudes toward cars compared with electronics.

The average car longevity in Europe is 8-35 years, with Luxembourg and Poland being at each end of the scale.[134] In Norway, the average is 14 years. Consumers expect a car to need regular maintenance efforts and significant repair costs as it ages. It is also common for a car to change ownership at least once in its lifetime, and it is regulated that components shall be taken out and re-used or recycled to a 95% effect when the useful life is ended. It is different from the expectations towards a TV screen or a washing machine despite such equipment often having similar life expectancy. If these pieces of equipment fail, they are more often replaced than repaired, and maintenance efforts, even minor ones such as vacuuming out dust or cleaning clogged filters, are rare. This was different a few decades ago and might be different again a few years ahead. There are no reasons that capital goods such as computers or mobile phones should be distinct and perform differently than cars.

For instance, in a snapshot from the Norwegian platform Finn, there were 64,014 ads on December 1st for the sale of secondary cars, while at the same time, 114,807 ads for car parts sales. Properly nudged, achieving similar figures for the EE sector should be possible.

To help the market, essential things such as restrictions on glues and accessibility of repairs as described in the Eco-design directive are needed. However, CRM-containing components should be marked/labelled/coloured specifically, making it easier and faster to identify and sort.

It is also possible to standardise some general components. EU has tried this before with power chargers. It could also be done with other CRM-rich components, such as resistors and perhaps even capacitors.

Reusing tantalum capacitors is surprisingly uncommon, considering prices, supply constraints and longevity. Tantalum is one of the most interesting elements in electronic waste, with easy-to-identify components, a high concentration of tantalum in the capacitors and a high price. Still, all industry efforts have been focused on sorting these capacitors for chemical recycling. Chemical processing and recycling have proven difficult,[135] but possible,[136] and strangely, direct re-use is less prevalent.

Tantalum capacitors do not lose much efficiency during use, so if the recycling industry can find new ways to dismantle,[137] control and re-use them they will open exciting industrial options. Fleet tests by NASA[138] has shown that while traditional tantalum capacitors have had an issue with a high failure rate early in their lifespan despite their otherwise long lifespan, newer technologies have solved the infant failure issue by sacrificing longevity. Still, it is expected that modern tantalum polymer capacitors should have a lifespan of 20 years,[139] which is far longer than the operational life of the equipment in which it is used. It is expected that even short-lifetime capacitors should be able to be used 2-4 circles before being chemically recycled.

134. Held, M. et al 2021. Lifespans of passenger cars in Europe. European Transport Research Review.
135. Choi, B. et al 2023. Sust. recycling process for tantalum recovery from PCBs. Resources, Cons. and Rec.
136. Mir, S. et al 2023. Recycling of metallic values from discarded tantalum capacitors. Mineral Proc. and Extractive Met.
137. Riedewald, F. et al 2023. Tantalum Capacitor Separation from Waste PCBs with Molten Salt or Metal. Chemie Ingeniuer Teknik.
138. https://nepp.nasa.gov/docs/tasks/003-Evaluation-Polymer-Tantalum-Capacitors-for-Space-Applications/2022-Teverovsky-CMSE-Presentation-20220005554.pdf
139. https://hongdacap.com.hk/news/How-long-do-tantalum-capacitors-last.html

Figure 2.10 Capacitors, resistors, diodes, and rectifiers are all based on CRMs, and can be dismantled for re-use or recycling if WEEE is transported and dismantled carefully. Photo: AdobeStock.

Rectifiers are used to convert alternating current to direct current in electronics. In contrast to many other components, it is often installed as a plug-in and only sometimes soldered into the PCB. A relatively common rectifier material is the dielectric compound neodymium titanate – a heritage from the old days when neodymium was a waste product from cerium production. As neodymium titanate rectifiers are solid components with long lifespans, they have been considered possible for re-use for decades.[140] Amongst suppliers of rectifiers, several of them supply used/second-hand rectifiers in parallel with new ones. However, standardisation and cheap new products have pressured the marketing attractiveness of the used pieces.

LED, the tiny diodes that have taken over the world of illumination within a few years, have been fantastic for reducing energy consumption and cost to consumers. With useable lifespans of 20-100.000 hours or more,[141] they have reduced material consumption significantly. However, new recycling issues have been introduced since LED is based mainly on gallium, indium, arsenic, and rare earths.

With its long lifespan, LEDs used in screens, phones, laptops, and other small and large electronic equipment have yet to reach their possible lifespan when the laptop, mobile phone, washing machine, TV or screen is discarded. As the diodes are so small and regularly hard-fixed to other components, dismantling, recycling, or reusing them is rarely seen as worthwhile.

140. Beak, J. et al. Reusing and Rerating Older Rectifiers With New DC/DC Choppers. IEEE 2001.
141. https://insights.samsung.com/2022/05/23/the-truth-about-led-lifespan-and-the-longevity-of-your-display/

It is shown that more than 50% of faulty LED systems can be repaired and fully functional again,[142] a strong argument for having systems in place where diodes are picked off and used to repair other LED equipment.

The most crucial single barrier to LED recycling has been identified as glue.[143] If it is important to be able to re-use single diodes, the first thing on the to-do list will need to be strict restrictions on gluing and other methods that complicate dismantling and sorting.

In parallel, improved technologies and procedures for dismantling glued and fixed diodes must be developed. Then standardised procedures for testing of diodes should be developed to sort between eligible for re-use or recycling.[144] It is common that a faulty LED link is removed and replaced entirely, despite only the driver being worn out and needing replacement.

Previously, an active industry existed for dismantling silicon chips from PCBs. The boards were placed on a bed of molten tin, allowing chips to be removed with pinchers or tweezers for direct re-use. Despite such chips being in shorter supply in recent years compared to the period when this practice was more widespread, this re-use industry seems to be no longer active. The decline is likely due to its labour-intensive nature; as the value of chips decreases and labour costs rise, the economic feasibility of re-use – similar to recycling – becomes less viable.

Resistors are the small dull pieces with colour codes you will find all over a printed circuit board. They can be easily spotted as small and bar-coloured pieces that have important functions. They are however rarely if ever reused although even simple and low CRM resistors have a lifetime of 15-20 years. Some advanced resistors based on ruthenium have been argued to have a life span potential of 48,000 years.[145] Ruthenium is primarily sourced from South Africa. During a strike in the platinum industry in 2021, global prices of ruthenium doubled, and production of resistors was severely reduced – showing how even minor disturbances to the supply line can have significant consequences down the line.

Amplifiers are in a similar situation. While these components typically contain fewer CRMs, they still have substantial longevity and increased re-use potential.

Used EE equipment is delivered and collected as scrap material without considering the residual value of its components. While new equipment is supplied in large cardboard boxes with all kinds of protection, used equipment is delivered and collected as is, and it is reasonable to expect that just the transportation and handling of the equipment from the delivery point to the sorting reduce the re-use and replacement value significantly.

All the Nordic countries have well-functioning EPR systems and professional service providers. However, these systems were initially established to avoid toxic materials from WEEE entering the environment and regular waste streams and have gradually had an increasing role regarding the recycling of metals such as copper. However, these EPR systems have no obligation or mandate to promote or subsidise the re-use or repair of equipment or components.

There are two significant shortfalls of the EPR systems for electronics in the Nordics that should be addressed also to achieve increased re-use. The general exceptions given to the automotive sector have held a large volume of the CRM-containing electronics out of the loops and systems required for all other equipment, making it harder to optimise re-use and recycling.

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142. Pujolras, B.C. Design and Implementation of a Procedure for Collecting and Repairing Faulty LED Bulbs. Diss. 2024.
143. Chamberlain, M. Re-purposing LED Light bulbs. B.Sc. dissertation 2022.
144. Mehvie, M. Et al. Characterization of end-of-life LED lamps: Evaluation of reuse, repair and recycling potential. Waste Management 2022.
145. www.akaneohm.com/english/column/the-lifetime-of-a-metal-glazed-film-resistor-is-48000-years/

Also, the EPR requirement to achieve recycling by tonnes of material does not incentivise efficient re-use and does not incentivise recycling or handling of small volumes of highly critical metals. Indeed, while it is good for the environment that HIPS, steel and aluminium are recovered efficiently, there is a need for a general overhaul of the EPR framework.

Potential for substitution/waste reduction of critical raw materials

Most components in WEEE delivered for recycling are far from their end of life span when the product is discarded. Based on available test results, it can be assumed that > 50% of components are eligible for re-use. However, a substantial improvement in collection, transportation, sorting, dismantling, testing and remanufacturing is needed to achieve anywhere close to this technical potential.

Barriers

As price/value is most likely a primary driver for well-functioning re-use schemes, low prices can be a key barrier. If a component or piece of equipment costs 10 Euro, spending time and money on checking performance and trading it might not be worthwhile, while if it costs 1,000 Euro it will very often be profitable.

Lack of competence. Only a few people can identify/repair/change EE components from a broad range of equipment.

Possible means of actions/instruments

Tax or deposits on EE-products to fund more detailed equipment testing and component picking.

Increase the VAT on new EE equipment to subsidise operations necessary for reuse

Remove VAT from all secondary products and all repair services. Remove wealth tax for ownership of secondary products in stocks.

Automatic “amnesty” from waste legislation for any functioning component removed from discarded equipment for re-use. for instance simplified “end of waste” procedure.

Mandate sales guarantees to be upheld even if equipment is opened for repair and removal of components.

Government sponsored training of employees on recycling hubs and -stations regarding identification, safe removal and handling of components.

Consider legislation requiring recycling companies to check each received item individually for reusability or repair/component re-use.

Changes in the national taxation system that decreases the cost of labour and increases the cost of natural resources and energy will also incentivise repair and re-use.[146]

Promote schemes where second-hand laptops are checked, repaired and, updated and sold inexpensively to schools.[147]

Support development program for new methods of connecting tantalum capacitors, making them easier to remove without destruction.

Mandate removal of all electric equipment and electronics from scrapped automobiles, including the dismantling of useable components, copper and optics cables, screens, tiny motors, etc, before shredding.

146. www.regjeringen.no/no/dokumenter/nou-2015-15/id2465882/
147. https://www.dn.no/teknologi/sparer-75-prosent-pa-a-kjope-brukte-pc-er/1-1-1830976

Incentivise the EPR systems to support increased sorting and re-use.

Impose quantitative minimum targets of re-use for the EPR schemes.

Support the social enterprises that organise the repair and distribution of used electronics and by that, both supply employment and equipment to less fortunate people.[148]

Ban the destruction of unsold virgin EE equipment. Mandate either price cuts or the delivery to NGOs active in the handling of used equipment.

Socio-economic impact

Reusing electronic components is already a substantial and growing part of the circular economy. Partly based on professional dismantling, sorting and reselling from specialised recycling companies and partly on private persons selling directly online. The sizes of these markets are not quantified but are assumed to be substantial.

Having existing systems that work autonomously is a privilege in the circular economy, so it is essential to stimulate the growth and maturing of these markets and avoid regulations that will limit their productivity.

Other variants of the measure

This chapter contains a long list of possible measures that can be considered and implemented both individually and collectively. Only some of the measures are dependent on other measures.

2.2.4 Consider increased use of second-hand products or assisted repair service in insurance settlement cases

Table 2.14 Summary of the measure: Consider increased use of second-hand products or assisted repair service in insurance settlement cases

Objective and intended effect/expected impact	Implementation	Feasibility and evidence
By providing used products or assisted repair services as compensation in insurance settlements CRMs used in the production of new products that are being replaced can be saved for other uses. Although this practice already existis in the insurance industry it is so far an exception rather than a norm, and the potential for expansion of this practrice should be considered.	Increased replacement of lost products covered by insurance policy with used alternatives or assisted repair services can be expanded as either as a vuluntary or compulsory scheme.	The cost of providing a reused product with acceptable properties or adequate repair services will probably often be more costly than pruchasing a new product. A compulsory scheme is also expected to be less popular among policy holders.

148. https://rreuse.org/rreuse-supports-minimum-requirements-for-a-professional-weee-preparing-for-re-use-sector/

Many insurance services protect the policy holders against loss or damage of property including CRM-containing products. When a legitimate claim that is covered by the policy is made, a financial compensation is given to the policy holder. The compensation paid by the insurance company for a lost product claim usually considers the age and constitution of the lost product and only covers the remaining value of the product at the time it was lost. The compensation is however most often provided as a cash payment, and nothing prevents the policyholder from buying a new product by covering the financial intermediary from their own funds. Buying a used product is often more cumbersome compared to purchasing a new one and doesn't always come with the same right of complaint or guaranteed lifetime associated with new products. This may also lead many policyholders to prefer replacing the lost product with a new one, although the compensation only covers a used alternative.

If the insurance service instead of a cash compensation provided a used product replacement service as part of the compensation this could both simplify the purchasing process and reduce the risk for the policyholder of replacing the lost product with a less than acceptable substitute. This practice already exists in the insurance industry but as an exception rather than a norm. By increasing the frequency of claim settlements where damaged products are being repaired rather than discarded or replaced by second-hand alternatives instead of new products consumption of significant amount of CRMs could be avoided through the new products that are avoided.

Insurance services that commonly cover CRM-containing products that could be replaced by used alternatives include contents insurance and travel insurance. CRM-containing products that are often replaced during contents and travel insurance compensations include phones and other electronic equipment, household appliances, sport and hiking equipment, bicycles, tools and jewellery. Car insurance is not considered to be as relevant because the used car market is already well developed.

If the insurance company also provided a repair service for damaged products, this could perhaps restore a higher number of damaged products for continued use compared to the policyholder pursuing such services on their own.

Potential for waste reduction of critical raw materials

Based on Norwegian insurance statistics, assuming similar insurance markets in other Nordic countries and extrapolating from population sizes the number of Nordic insurance settlements and paid insurance compensations are estimated in table 2.15.[149]

149. https://www.finansnorge.no/tema/statistikk-og-analyse/forsikring/nokkeltall-skadeforsikring/#skader

Table 2.15 Estimated number of settlement cases and total paid compensations in Nordic insurance industry in 2023 that may involve lost CRM-containing products that could potentially be replaced by used alternatives. Source: Bergfald Miljørådgivere

	Number of cases	Paid insurance compensation (MNOK)
Nordic contents insurance	1.791.761	9.968
Nordic Travel insurance	9.056.535	10.604
Total	10.848.296	20.572

If one assumes that half of the total number Nordic contents and travel insurance settlements in 2023 involves replacement of a single CRM-containing product that could potentially be replaced by a used alternative, then this represents more than five million transactions where a used alternative replaces a new CRM-product. If each transaction involves a product containing on average 100 g of CRMs, then products containing 500 tonnes of CRM will be covered by the scheme. If one assumes that half of the compensation paid by the insurance companies covers these products, the market value of these replacements will be more than 5 billion NOK.

Barriers

An insurance service that limits the options for how the policy holders can utilize the compensation from a settlement may struggle to compete with cash payback insurance services in the market unless it is cheaper. As working costs are comparatively higher to material costs in the Nordic countries, a service that moves from a material intensive scheme towards a more work intensive scheme will therefore often experience increased operational costs. An insurance compensation scheme using second hand products and assisted repair services may therefore be both less profitable and less popular with customers than conventional insurance services.

The insurance industry is heavily regulated both on a regional and national level, and there may therefore also be regulatory limitations on how far circular solutions to insurance claims may be taken. The European insurance regulations, that include the Insurance Distribution Directive (IDD) seeks to harmonize insurance practice in Europe and may contain provisions that limit how settlements can be organized.

Possible means of actions/instruments

A more resource efficient insurance scheme can focus on both second-hand products and assisted repair services, or only one of these options during settlements. This scheme can be either voluntary or compulsory. Existing insurance policies regulates how compensation can be made, and radical changes in this practice can most likely not be implemented for current insurance customers until these insurance policies are updated.

Socio-economic impact

From a CRM-resource perspective increased use of second-hand products and assisted repair services in the insurance industry as compensations for accepted claims will reduce the need for CRM materials in the new products that are displaced. As increased reuse and repair is more labour intensive, this can also be expected to create additional jobs.

3. Conclusion

Tables 3.1 and 3.2 summarise the measures discussed in Chapter 3.

Table 3.1 Overview of potential measures for CRM-waste prevention.

Instruments and measures for waste prevention			
Name of initiative	**Objective and intended effect/expected impact**	**Implementation**	**Feasibility and evidence**
Reduced use of helium for entertainment purposes	Helium is produced as a by-product of natural gas, and its supply is therefore expected to decline as fossil fuels are phased out globally. The gas has important industrial and technical applications, as well as being widely used for entertainment purposes. Banning or restricting its use for entertainment purposes would increase security of supply for more important uses. 20 % of todays helium use can be avoided through a ban on party balloons. Changes in MRI-practice can limit the helium use further.	Ban helium use in party baloons, increase collection of helium from MRI-machines and increase use of helium free MRI-machines will reduce depletion of limited helium reserves and future supply risk. A national ban on helium should be set by governmental authorities. Helium recycling from MRI-machines should be required where possible. A economic deposit on helium use for other purposes can finance recycling schemes to ensure helium recycling from other applications.	Although local iniatives have been tried out or proposed, no national action has so far been taken by Nordic countries.
Reduced use of aluminum for packaging purposes	Significant amounts of aluminium are used as single-use packaging where alternative materials are often available. A ban or restriction on the use of aluminium for non-essential packaging purposes would reduce the overall consumption of aluminium that ends up in waste streams with limited recycling potential. As magnesium is used as an alloying additive in many aluminium alloys for packaging purposes, the same measure would also minimise magnesium consumption for the same purpose. Substitution of aluminum packaging where acceptable material alternatives exist can reduce Nordic aluminum consumption by almost 20 000 tonn anually.	Stimulate PSS-businesses reusing aluminium packaging, plates and trays. Ban the use of aluminum metallization of polymers for packaging of consumer products. Ban the use of aluminum foil for chocolate and confecionary products. Ban use of blister packaging of pills and capsules, with exceptions for medically required use. Support development of new aluminum can systems less dependent on dilution. Information campaigns to both industry and the public on most optimal use of different packaging materials. Unless introduced as a regional ban by EU, each ban should be set nationally by relevant governmental authorities.	No national initatives has so far been identifed.

Eliminate the use of coke in steel production	Metallurgical coke is used as a reducing agent in the production of iron and steel. An alternative production method where hydrogen and electricity replace coke in the process is available through Direct Reduction (DRI). DRI-plants are being planned in Sweden through the Hybrit and H2Gsteel projects.	Establishment of DRI furnaces that can replace and blast furnaces should receive both economic and legislative governmental support. While hydrogenbased DRI is the optimal non-emission infrastructure, even natural gas based DRI will dramatically reduce emissions – and will eliminate the need for coke. Implementation of strict CBAM tariffs around Europe, to avoid unfair competition should also be be done.	DRI-plants are operational world wide, and planned in Sweden.
Adopt alternative technology for the primary production of aluminum that eliminates the need for fluorine and anode graphite	A number of alternative processes for the production of primary aluminium that could result in increased recycling or reduced need for CRMs as feedstocks are under development. Aluminium production using inert anodes would limit the need for graphite in the process, aluminium production with anorthosite would yield pure silica as a by-product, and aluminium production based on a chlorine-based salt melt would eliminate the need for fluorine for the same purpose while also enabling the extraction of trace amounts with CRMs other than aluminium. By supporting the development of these technologies, aluminium production could become far more CRM resource efficient.	Governmental support for pilots and demonstration plants for alternative production of primary aluminium. Governmental economic support schemes should be considered either thorugh CAPEX payments or loans/ grants.	Technolgies have been tested in pilot plants
Reduced use of copper for chemicals	Thousands of tons of copper metal are removed from secondary value chains in the Nordic countries to become preservatives, biocides and pigments. This copper cannot be recycled, although some of the copper is found in incineration ashes. There are good substitutes for many of these applications. A ban or restrictions on the use of copper-based preservatives, biocides and pigments would not only minimise the Nordic consumption of copper by as much as 16 000 tons anually, but can also contribute to an increased copper recycling rates.	The following restriction should be considered: Ban against the use of copper for timber preservative, with some possibility of legal exemptions. Ban against the use of copper for fish farming infrastructure. Ban use of copper fungicides for non-essential farming, such as flowers and Christmas decorations. Ban the use of copper and all other CRMs in printing inks, textile dyes and pigments for polymers and paints. Tariff or tax on use of all legal copper chemicals to increase price and incentivise reduced consumption should also be considered. Information campaign that raises public awareness about the negative CRM-implications of copper chemicals.	No national initatives has so far been identifed.

Reduced use of REE for pigment, ceramic products and glass production	Thusands of tons of REE are being used in glass and ceramics worldwide as pigment where these CRMs are lost for future recovery. A ban or tax on the use of strategic REEs like neodymium and praesodymium in pigments, glass and ceramics could minimize the proportion of these REEs used for this purpose, and thus reduce supply risks for more essential high-tech applications.	A Nordic ban on strategic REE in glass and ceramics will have limited effect. In stead such restrictions on a European level should be proposed. Restrictions on neodymium and praesodymium are especially important.	No national or regional initatives has so far been identifed.
Reduced use of CRMs for fireworks	Restrictions on fireworks could reduce the use of barium, magnesium and strontium, and thus improve the security of supply of the same raw materials for high-tech applications.	A national ban on fireworks should be introduced. Alternative an additional tax on fireworks that limit consumption or information campaign that raises public awareness about negative CRM-implications and littering problems caused by fireworks.	Countries such as Ireland and Chile , along with the U.S. state of Massachusetts , have enacted a general ban on all private use of fireworks.
Reduced use of critical raw materials in small electronics in consumer products	Significant amounts of small electronics are included in consumer products. A common feature of much of this small electronics is that it is integrated into textiles, toys, sporting goods and leisure equipment such as sneakers, which makes sorting difficult and is therefore less likely to be recycled than other EE waste. A ban on or excise duty on the use of critical raw materials for non-essential consumer products could minimise the proportion of CRM used for this purpose, and thus improve the security of CRM supply for high-tech applications.	Ban products with unnecessary electronic components including textiles with light, sensor, and microchips. Alternative an additional tax on such products that limit consumption or information campaign that raises public awareness about negative CRM-implications these products.	No national or regional initatives has so far been identifed.
Increase the number of CRMs and overall extraction efficiency from ore mined in the Nordic region.	Critical raw materials such as copper, cobalt and nickel are included as by-products that are often not extracted from ore processed in the Nordic region. More advanced beneficiation techniques have the potential to extract more of these CRMs from beneficiation processes, thereby minimizing the waste materials that subsequently need to be landfilled.	Restructuring taxation of Nordic mining industry to insentivice increased extraction of CRM-byproducts from processed ore.	No national or regional initatives has so far been identifed.

Table 3.2 Overview of potential measures for re-use of CRM-containing products and components.

Instruments and measures for reuse			
Name of initative	**Objective and intended effect/expected impact**	**Implementation**	**Feasibility and evidence**
Assess the possibility of reusing optical cables with CRM content	Reusing germanium-containing optical cables could reduce the need for germanium for this purpose. Optical cables can also contain other CRMs, such as REE.	A system for collection and preparation of end-of-life optical cables for re-use should be considered.	No national or regional initatives has so far been identifed.
Reusing magnets in electric motors, pumps and "dynamos"	Reusing electric motors in pumps and other electrical components, or the magnets they contain, could reduce the need for new magnetic metals of the same type. However, material fatigue will limit the reuse possibilities for certain components. Proper testing of the components is therefore important before re-use. The scheme should perhaps be limited to manufacturers only recalling their own products.	Encourage standardization of magnet chemical composition, design form and size that supports reuse of magnets in new generations of products. Support magnet reuse schemes in industry	Some legislation regarding these issues are expected to follow from CRMA
Reusing CRM components in discarded EE products	There is already an established market for still usable components stripped from end of life electronic products. This market can be further developed. CRM components such as magnets (REE), vibrating elements (W), capacitors (Ta) may be used in new products or as spare parts during repairs.	Support reuse of electronic components through tax incentives and collection schemes	No national or regional initatives has so far been identifed.
Increasing the number of insurance settlement cases where used products or assisted repair services are provided as compensation in stead of new products.	By providing used products or assisted repair services as compensation in insurance settlements CRMs used in the production of new products that are being replaced can be saved for other uses. Although this practice already existis in the insurance industry it is so far an exception rather than a norm, and the potential for expansion of this practrice should be considered.	Increased replacement of lost products covered by insurance policy with used alternatives or assisted repair services can be expanded as either as a vulountary or compulsory scheme.	The cost of providing a reused product with acceptable properties or adequate repair services will probably often be more costly than pruchasing a new product. A compulsory scheme is also expected to be less popular among policy holders.

Abbreviations

Al	Aluminium
As	Arsenic
B	Boron
Be	Beryllium
BRICS	Brazil, Russia, India, China, South Africa
C	Carbon
CAPEX	Capital expenditures
Co	Cobalt
CRM	Critical Raw Material
CRMA	Critical Raw Material Act
Cu	Copper
DRI	Direct Reduction Plants
Dy	Dysprosium
EAF	Electric Arch Furnace
EEE	Electric and electronic
EEA	European Economic Area
ELV	Life Vehicle
EPR	Extended Producer Responsibility
Er	Erbium
Eu	Europium
EV	Electric Vehicle

F	Fluorine
Ga	Gallium
Gd	Gadolinium
Ge	Germanium
He	Helium
HIPS	High Impact Poly Styrene
Ho	Holmium
HREE	Heavy Rare Earth Elements
ICE	Internal Combustion Engine
Ir	Iridium
La	Lanthanum
Li	Lithium
LREE	Light Rare Earth Elements
Lu	Lutetium
Mg	Magnesium
Mn	Manganese
MRI	Magnetic Resonance Imaging
MSWI	Municipal Solid Waste Incineration
Nb	Niobium
Nd	Neodymium
Ni	Nickel
NIB	Neodymium Iron Boron magnet
OPEX	Operational expenditures
P	Phosphorous

Pd	Palladium
PCB	Printed Circuit Board
PGM	Platinum Group Elements
ppm	parts per million
Pr	Praseodymium
Pt	Platinum
Re	Rhenium
REE	Rare Earth Elements
Rh	Rhodium
Sb	Antimony
Sc	Scandium
Si	Silicon
Sm	Samarium
Ta	Tantalum
Tb	Terbium
Ti	Titanium
Tm	Thulium
V	Vanadium
W	Tungsten
WEEE	Electric and electronic waste
Yb	Ytterbium
Y	Yttrium

Appendix

Table 1 Overview over possible measures for CRM waste prevention.

ID	Name	Supplementary explanation	Justification and expected effect
	CRM waste prevention		
A1	Reduced use of antimony as a flame retardant	China has recently stopped exporting antimony to the West, creating a bottleneck for the production of ammunition for Ukraine. Bans or restrictions on antimony for non-essential purposes are therefore more relevant than ever. A ban on the use of antimony as a flame retardant will force the use of alternative substances for the same purpose	Reduced need for antimony
A2	Reduced use of helium for entertainment purposes	Helium is produced as a by-product of natural gas, and its supply is therefore expected to decline as fossil fuels are phased out globally. The gas has important industrial and technical applications, as well as being widely used for entertainment purposes. Banning or restricting its use for entertainment purposes would increase security of supply for more important uses. 20 % of todays helium use can be avoided through a ban on party balloons. Changes in MRI-practice can limit the helium use further.	Reduced need for helium
A3	Reduced use of aluminum for packaging purposes	Significant amounts of aluminium are used as single-use packaging where alternative materials are often available. A ban or restriction on the use of aluminium for non-essential packaging purposes would reduce the overall consumption of aluminium that ends up in waste streams with limited recycling potential. As magnesium is used as an alloying additive in many aluminium alloys for packaging purposes, the same measure would also minimise magnesium consumption for the same purpose. Substitution of aluminum packaging where acceptable material alternatives exist can reduce Nordic aluminum consumption by almost 20 000 tonn anually.	Reduced need for aluminium and magnesium
A4	Reduced use of aluminum as constrution material	Aluminum is used as a construction material to a significant extent in the building and infrastructure, including as facade panels. A ban or restrictions on the use of aluminum for construction purposes would increase the security of supply of aluminum to the transportation sector, where the metal's low material density is even more important.	Reduced need for aluminium

A5	Reduced use of boron in soaps and non-essential pharmaceutical products.	Boron is used as an ingredient in many soaps and pharmaceutical products, where after use it largely ends up in wastewater, making recycling difficult. A ban or restrictions on the use of boron in non-essential pharmaceutical products would minimize boron consumption.	Slightly minimized need for boron
A6	Reduced use of bismuth in non-essential pharmaceutical products.	Bismuth is used as an ingredient in many pharmaceutical products, where after use it largely ends up in wastewater, making recycling difficult. A ban or restrictions on the use of bismuth in non-essential pharmaceutical products would minimize the consumption of bismuth	Reduced need for vismut
A7	Eliminate the use of coke in steel production	Metallurgical coke is used as a reducing agent in the production of iron and steel. An alternative production method where hydrogen and electricity replace coke in the process is available through Direct Reduction (DRI). DRI-plants are being planned in Sweden through the Hybrit and H2Gsteel projects.	Reduced need for coke
A8	Adopt alternative technology for the primary production of aluminum that eliminates the need for fluorine and anode graphite	A number of alternative processes for the production of primary aluminium that could result in increased recycling or reduced need for CRMs as feedstocks are under development. Aluminium production using inert anodes would limit the need for graphite in the process, aluminium production with anorthosite would yield pure silica as a by-product, and aluminium production based on a chlorine-based salt melt would eliminate the need for fluorine for the same purpose while also enabling the extraction of trace amounts with CRMs other than aluminium. By supporting the development of these technologies, aluminium production could become far more CRM resource efficient.	Reduced need for fluor og grafitt
A9	Eliminate the use of fluorinated organic chemicals	Fluorinated organic compounds have countless applications, including in the form of the materials Goretex and Teflon, and as the highly environmentally harmful substance group PFAS which is in the process of being banned by the EU. A ban or restrictions on fluorinated compounds for non-essential purposes would not only limit the consumption of fluorine for purposes that make recycling difficult, but also reduce the spread of environmentally harmful substances.	Slightly minimized need for fluoride
A10	Reduced use of gallium for ski lubrication	Gallium-based ski lubrication has been launched as an expensive alternative to conventional ski lubrication. A ban or restrictions on gallium-based ski lubrication would limit the consumption of gallium for this purpose.	Slightly minimized need for galium

A11	Reduced use of copper for chemicals	Thousands of tons of secondary copper are removed from secondary in the Nordic countries to become preservatives, biocides and pigments. This tonnage cannot be recycled, although some of the copper is found in incineration ashes. There are good substitutes for many of these applications. A ban or restrictions on the use of copper-based preservatives, biocides and pigments would not only minimise the Nordic consumption of copper by as much as 16 000 tons anually, but can also contribute to an increased copper recycling rates.	Minimized need for copper and increased recycling rate
A12	Reduced use of neodymium for ceramic and glass production	A ban or tax on the use of neodymium in glass production could minimize the proportion of neodymium used for this purpose, and thus improve security of supply for high-tech applications.	Reduced need for neodymium
A13	Reduced use of dysprosium for glass production	A ban or tax on the use of dysprosium in glass production could minimize the proportion of dysprosium used for this purpose, and thus improve the security of supply for high-tech applications.	Reduced need for dysprosium
A14	Reduced use of ytterbium for glass production	A ban or tax on the use of ytterbium in glass production could minimize the proportion of ytterbium used for this purpose, and thus improve security of supply for high-tech applications.	Reduced need for ytterbium
A15	Reduced use of terbium for glass production	A ban or tax on the use of terbium in glass production could minimize the proportion of terbium used for this purpose, and thus improve security of supply for high-tech applications.	Reduced need for terbium
A16	Reduced use of preasodynium as a pigment and in ceramic products	A ban or tax on the use of praesodymium in glass production could minimize the proportion of praesodymium used for this purpose, and thus improve security of supply for high-tech applications.	Reduced need for praesodymium
A17	Reduced use of lithium for glass and ceramic products	A ban or excise tax on the use of lithium for glass and ceramic products could minimize the proportion of lithium used for this purpose, and thus improve the security of supply of batteries.	Reduced need for litium
A18	Reduced use of nickel-steel alloys in consumer products	Nickel is used in many steel alloys used in consumer products. Bans or excise taxes on the use of nickel-steel alloys for non-essential purposes could minimize the proportion of nickel used for these purposes.	Reduced need for nickel
A19	Reduced use of PGM metals in jewelry	A ban or tax on the use of PGM metals for jewelry could minimize the proportion of PGM used for this purpose, and thus improve the security of supply of PGMs for high-tech applications.	Reduced use of PGM-metals

A20	Reduced use of CRMs for fireworks	Restrictions on fireworks could reduce the use of barium, magnesium and strontium could reduce the loss of these CRMs used for this purpose, and thus improve the security of supply of the same raw materials for high-tech applications.	Reduced use of barium, strontium og magnesium
A21	Reduced use of titanium in consumer products	A ban or tax on the use of titanium for non-essential consumer products such as sporting goods and the like could minimize the proportion of titanium used for this purpose, and thus improve the security of supply of this metal for high-tech applications.	Reduced need for titanium
A22	Reduced use of critical raw materials in small electronics in consumer products	Significant amounts of small electronics are included in consumer products. A common feature of much of this small electronics is that it is integrated into textiles, toys, sporting goods and leisure equipment such as sneakers, which makes sorting difficult and is therefore less likely to be recycled than other EE waste. A ban on or excise duty on the use of critical raw materials for non-essential consumer products could minimise the proportion of CRM used for this purpose, and thus improve the security of CRM supply for high-tech applications.	Reduced CRM-needs
A23	Increase the number of CRMs and overall extraction efficiency from ore mined in the Nordic region.	Critical raw materials such as copper, cobalt and nickel are included as by-products that are not extracted from ore processed in the Nordic region. More advanced beneficiation techniques have the potential to extract more of these CRMs from beneficiation processes, thereby minimizing the waste materials that subsequently need to be landfilled.	Increased CRM production and minimization of waste materials
A24	Extend the life of mobile phones	The lifespan of mobile phones can potentially be extended through, among other things, new product design requirements, longer warranty periods, better disassembly options and well-established and affordable repair services, preferably with VAT exemption. Repair schemes can be considered as part of existing EPR agreements.	Reduced CRM-needs
A25	Extend the life of tablets, TVs, PC monitors, servers and data storage devices	The lifespan of tablets, TVs and PC monitors can potentially be extended through, among other things, new product design requirements, longer warranty periods, better disassembly options and well-established and affordable repair services, often with VAT exemption. Repair schemes can be considered as part of existing EPR agreements.	Reduced CRM-needs
A26	Extend the product life of batteries	The lifespan of batteries can potentially be extended through, among other things, new product design requirements, longer warranty periods, better dismantling options and well-established and affordable repair services, preferably with VAT exemption. Repair schemes can be considered as part of existing EPR agreements.	Reduced CRM-needs

A27	Raise knowledge and consumer awareness about opportunities for waste minimization and repair of CRM-containing products	A prerequisite for more efficient schemes for waste prevention and reuse of CRM-containing products is that the Nordic population has knowledge of available schemes for this, and is motivated to use them. A public awareness campaign around this could be instrumental in achieving this. In addition, strategies for more comprehensive education about critical raw materials and the associated waste hierarchy in primary and secondary education should be considered.	Better knowledge and motivation for using schemes that minimize CRM-containing waste.
A28	Distribution scheme for the supply of affordable spare parts to repairers of EEE products	Well-functioning repair schemes require the availability of spare parts that enable the replacement of defective and obsolete components. Establishing a national scheme for intermediate storage and distribution of parts that are frequently replaced during the repair of EEE products can contribute to faster and more cost-effective repair services for such CRM-containing products.	Faster and more efficient repair services for CRM-containing products.
A29	Arrangement that ensures that relevant spare parts are available for a reasonable period after CRM-containing products are no longer placed on the market.	When a product is discontinued, the production of associated spare parts often ceases. Arrangements should therefore be considered that ensure that manufacturers and importers are required to ensure that such spare parts continue to be available for the expected product life of existing products after production has ceased. This could, for example, be done by authorities drawing up lists of which spare parts are concerned and setting a maximum response times for delivery.	Faster and more efficient repair services for CRM-containing products.
A30	Establish bypass arrangements for part pairing that remove barriers for repairment.	Many EEE products are equipped with part pairings that enable associated components to recognize each other. However, such functions can create problems during repair operations where new spare parts lack part pairing recognition. Bypass arrangements that circumvent this problem may therefore be important to have in place.	Faster and more efficient repair services for CRM-containing products.
A31	Downloadable instructions on relevant repair techniques	Repair of CRM-containing products can be simplified and streamlined by having readily available instructions for download on how to best carry out the repair. The information should also include advice on troubleshooting and diagnostics, as well as relevant contact information.	Faster and more efficient repair services for CRM-containing products.
A32	Establishment of a scheme for 3D printing of spare parts for the repair of CRM-containing products	It should be considered whether a scheme for 3D printing of spare parts for CRM-containing products can simplify access to such parts for repair operations.	Faster and more efficient repair services for CRM-containing products.

A33	Accelerated development of redesigned products and services that minimize CRM waste.	Developing better product designs and services that enable the minimization of CRM waste will in many cases require significant R&D efforts. National programmes and support schemes for this could accelerate this development.	Accelerated development of products and services that minimize CRM waste
A34	More detailed mapping of products and applications where existing CRM usage can be reduced or eliminated.	Countless CRM-containing products are placed on the Nordic market each year. A more detailed national investigation of products and applications where CRM use can be minimized could potentially identify significant opportunities for minimizing CRM waste streams that have so far been overlooked.	Reduced CRM-waste
A35	Product design that allows the products to be opened and dismantled.	Glued and welded products often make repair difficult because the repairer cannot reach the components that need adjustment or replacement. A requirement that CRM-containing products must be able to be easily opened and disassembled, for example by using detachable screws that can be operated with conventional tools and by personnel without special product expertise, can contribute to easier and more efficient repair of CRM-containing products.	Faster and more efficient repair services for CRM-containing products.
A36	Standardization of component usage in CRM-containing products between brands and across product generations	Many CRM-containing products, especially EE-products, have their useful life shortened as a result of the product or components that the product contains, such as charging functions, connection ports, displays, batteries, circuit boards, being or becoming incompatible with similar products of other brands or product generations. Increased standardization of components included in CRM-containing products could minimize this problem.	Longer product life of CRM-containing products
A37	Available software updates that enable continued use of the product after it has been discontinued	Certain CRM-containing EE-products require ongoing software updates to continue to function. A requirement for ongoing software updates for necessary upgrades of security and functionality for up to 10 years after the EE product is no longer placed on the market could contribute to an extended lifespan for these products.	Longer product life of CRM-containing products
A38	Consider accelerating the phase-out of hard disk drives (HDD) with solid state drives (SSD)	Traditional hard disk drives (HDD) are being phased out and are increasingly being replaced by solid state drives (SSD) which do not normally contain magnetic metals. An accelerated phase-out of hard disk drives (HDD) with solid state drives (SSD) could eliminate the need for magnetic metals (especially neodymium) but would also increase the total number of other critical raw materials required for the manufacture of the products. SSDs are also associated with a higher carbon footprint.	Reduced need for CRM magnets, but somewhat higher consumption of other CRMs

A39	Extraction of scandium from waste from titanium dioxide production	It is possible to extract an additional by-product in the form of scandium from waste from Nordic titanium dioxide production, and pilot projects for this are already underway.	Increased scandium supply and weakly minimized waste streams from titanium dioxide production
A40	Development of better training systems and simulators for weapons use in the defense sector	Development of better virtual training systems and simulators for weapons use in the armed forces could reduce the use of CRM-containing training ammunition and equipment.	Reduced need for antimony, copper bismuth, titanium, nickel etc.
A41	Restrictions on the use of digital screens	In recent years, the use of electronic displays for public information services and advertising purposes has exploded, and both buildings and vehicles including buses and rail cars are typically equipped with such displays. Restrictions on the use of electronic displays for non-essential uses, or where signage or timetable information can be done without, could limit the consumption of several CRMs.	Reduced use of gallium and REE.
	CRM reuse		
B1	Reuse of discarded facade panels and other aluminum materials in the construction sector	Many building elements in buildings that are demolished can potentially be reused in new constructions. Reusing aluminum building elements, such as facade panels, could reduce the need for new aluminum products for the same purpose.	Reduced need for aluminum in the construction sector
B2	Reuse of drilling fluid with barite	Barite is used as a weighting material in drilling fluids when drilling offshore wells in the petroleum sector. Discarded drilling fluids can potentially be reused when drilling new wells after upgrading.	Reduced need for barite for drilling fluids
B3	Reusing batteries	Discarded batteries with sufficiently high residual capacity can potentially be used in new products or for new purposes.	Reduced need for graphite, cobalt, lithium, manganese and nickel.
B4	Use of furnace gases from coke reduction processes for the production of CCU products	Furnace gas from closed furnace processes in the metal industry where coke is used as a reducing agent normally contains high levels of carbon monoxide (called synthesis gas) which can be used for the production of organic products including graphite, methane, methanol, ethanol and dimethyl ether in a CCU (Carbon Capture and Utilization) process.	Climate benefits as a result of using synthesis gas to manufacture new products.

B5	Assess the possibility of reusing fluorine for primary aluminum production	Discarded electrolytic fluid from furnaces producing primary aluminum contains significant amounts of fluorine. It should be considered whether electrolytic fluid currently discarded as waste can be upgraded in ways that enable new uses for the same purpose to a larger degree than what is already happening.	Reduced need for fluorine
B6	Assess the possibility of reusing optical cables with CRM content	Reusing germanium-containing optical cables could reduce the need for germanium for this purpose. Optical cables can also contain other CRMs, such as REE.	Reduced need for germanium
B7	Establish a collection scheme for the reuse of helium	A national collection scheme for used helium gas will enable the gas to be used for new purposes.	Reduced need for helium
B8	Reusing magnets in electric motors, pumps and "dynamos"	Reusing electric motors in pumps and other electrical components, or the magnets they contain, could reduce the need for new magnetic metals of the same type. However, material fatigue will limit the reuse possibilities for certain components. Proper testing of the components is therefore important before re-use. The scheme should perhaps be limited to manufacturers only recalling their own products.	Reduced need for new CRM magnetic metals.
B9	Increased reuse of CRM-containing car parts	Reuse of car parts is already happening on a large scale. Further reuse of car parts containing aluminum, magnesium, copper and other CRMs could reduce the need for new metals of these types.	Reduced CRM-needs
B10	Consider the possibility of increased reuse of steel components with CRM alloys	Increased reuse of steel components that contain, for example, manganese, niobium, nickel and/or vanadium alloys could reduce the need for new material of the same type.	Reduced CRM-needs
B11	Using phosphate-containing waste as fertilizer and soil improvement	Phosphate-containing waste can potentially replace artificial fertilizers.	Reduced need for phosphate
B12	Reusing discarded solar panels	When demolishing buildings, solar cells on roofs or integrated into the facade can be reused if schemes are developed for this.	Reduced need for solar cell silicon
B13	Reuse of discarded titanium consumer products	Increased reuse of consumer products made of titanium, such as sporting goods and eyeglass frames, could reduce the need for new titanium metal for the same purpose.	Reduced need for titanium

B14	Reusing CRM components in discarded EE products	There is already an established market for still usable components stripped from end of life electronic products. This market can be further developed. CRM components such as magnets (REE), vibrating elements (W), capacitors (Ta) may be used in new products or as spare parts during repairs.	Reduced CRM-needs
B15	Increasing the number of insurance settlement cases where used products or assisted repair services are provided as compensation in stead of new products.	By providing used products or assisted repair services as compensation in insurance settlements CRMs used in the production of new products that are being replaced can be saved for other uses. Although this practice already existis in the insurance industry it is so far an exception rather than a norm, and the potential for expansion of this practice should be considered.	Reduced CRM-needs
B16	Establish a recycling scheme for building materials and furniture	Many building materials and furniture contain critical raw materials. Establishing well-functioning reuse schemes for these materials and product groups can reduce the need for new CRMs	Reduced CRM-needs
B17	Establishment of a reuse scheme for discarded servers and data storage devices	Establishing well-functioning reuse schemes for servers and data storage devices could minimize the need for CRMs for production of new products of the same type.	Reduced CRM-needs
B18	Reuse of individual components in servers and other data storage devices	Establishing well-functioning reuse schemes for individual components, such as HDDs, memory cards, motherboards, CPUs, server chassis and data storage devices, could minimize the need for CRMs for the production of new components of the same type.	Reduced CRM-needs
B19	Secure and trustworthy data deletion schemes in connection with reuse schemes for EE products	When developing reuse schemes for EE products, it is important that these are accompanied by associated arrangements for secure and reliable deletion of historical data before the EE products change ownership.	User confidence in the reuse schemes and assurance that historical data does not end up astray
	CRM substitution		
C1	Develop neodymium-free rubber production.	Neodymium is used as a catalyst for the production of rubber, and large amounts of neodymium are lost as it follows the rubber material. Development of catalysts made of alternative materials could reduce neodymium losses, including in car tires.	Reduced need for neodymium

C2	Substitution of copper as a biocide and pigment	Thousands of tonnes of secondary copper are extracted from the technical material cycle for copper in the Nordic countries to become biocides and pigments. This tonnage is in practice lost, although some of the copper is found in incineration ashes. For all these purposes there are available substitutes. A ban or restrictions on the use of copper-based biocides and pigments will not only minimize the consumption of copper but also contribute to an increased recycling rate. The same measure is also found under waste minimization.	Reduced need for copper
C3	Substitution of lithium with sodium in batteries for stationary devices	Lithium in batteries can be replaced with sodium. However, this results in lower energy density, making sodium-based batteries most suitable for stationary devices where battery weight and volume are often less important.	Reduced need for lithium
C4	Finding alternative replacement materials for lithium in glass production.	By finding alternative materials that can replace lithium in glass production, a larger proportion of lithium will become available for battery production.	Reduced need for lithium
C5	Substitution of antimony and phosphorus-based flame retardants with other materials	There are alternative flame retardants that can replace antimony and phosphorus-based flame retardants.	Reduced need for antimony, and slightly reduced need for phosphorus.
C6	Substitution of antimony with other catalyst materials in the production of polyethylene phthalate plastic	Antimony is used as a catalyst in the production of polyethylene terephthalate plastic (PET). Calcium, tin and zinc are examples of materials that can potentially replace antimony for this purpose.	Reduced need for antimony
C7	Substitution of antimony with other pigments in the manufacture of glass	Tinn, krom, sink og zirkonium er eksempler på stoffer som kan erstatte antimon som pigment i glass.	Reduced need for antimony
C8	Substitution of boron in soaps and detergents	Boron can be replaced in some soaps and detergents with sodium or potassium salts or synthetic detergents.	Reduced need for boron
C9	Substitution of barite with alternative weighting agent in drilling fluid	There are alternative weighting agents that can replace barite in drilling fluids, such as ilmenite. These weighting agents often do not have the same favorable application properties however. Ilmenite is also a raw material for the production of another critical raw material (titanium metal).	Reduced need for barite

C10	Substitution of aluminum and magnesium with steel as a construction material in means of transportation	Aluminum and magnesium can in many cases be replaced by steel as a structural material in vehicles. However, this leads to increased weight and a correspondingly increased energy footprint.	Reduced need for aluminium og magnesium
C11	Increased substitution of cobalt with nickel in batteries	Substitution of cobalt with nickel in batteries is already happening. However, nickel is also a CRM.	Reduced need for cobalt
C12	Replacing coke with hydrogen in steel production	Metallurgical coke is used as a reducing agent in the production of iron and steel. An alternative production method where hydrogen and electricity replace coke in the process is available, and is being phased in in Sweden through the Hybrit and H2Gsteel projects, among others. The same option is also described under waste reduction.	Reduced need for coke
C13	Replacing copper in cables with alternative conductor materials such as aluminum and graphite	Copper can in some cases be replaced with alternative conductor materials, such as aluminum and graphite. However, as these materials have much lower electrical conductivity, this will result in higher energy losses during power transmission compared to copper. Aluminum and graphite are also CRMs.	Reduced need for copper
C14	Replacing copper in telecommunications with optical fibers	Copper can in some cases be replaced as a conductor material in telecommunications cables with optical fibers. However, optical fibers normally contain low concentrations of germanium which is also a CRM.	Reduced need for copper
C15	Replacing copper in drain pipes and heat exchangers with alternative materials	Copper in drain pipes can in many cases be replaced with copper-free material alternatives such as PEX plastic. Copper in heat exchangers can be replaced with alternative materials with slightly poorer thermal conductivity, such as aluminum or steel.	Reduced need for copper
C16	Develops copper-free brake pads for vehicles	Brake pads contain copper which is released into the environment during braking. Total European copper loss from brake pads is estimated at 2400 tonnes. Development of copper-free brake pads will eliminate this loss. Electric vehicles also use the engine for braking which can limit the load on the brake pads, although this is partly offset by the higher braking weight of electric vehicles.	Reduced need for copper
C17	Replacing feldspar with other mineral fillers in glass and ceramic materials	Feldspar can in some cases be replaced with other mineral fillers in glass and ceramic materials, such as nepheline. However, such substitution may result in less attractive material performance properties.	Reduced need for feldspat

C18	Replacing natural graphite with synthetic graphite	Synthetic graphite is not yet of sufficiently high quality to replace natural graphite for all purposes. Technological development will eventually provide synthetic graphite with improved performance properties that will make this possible.	Reduced need for natural graphite
C19	Replacing natural graphite with molybdenum oxide as a lubricant.	Natural graphite can in some cases be replaced with molybdenum oxide as a lubricant.	Reduced need for natural graphite
C20	Replacing rare earth elements in glass production and as pigments	Substitution of rare earth elements with alternative materials for the production of glass and ceramics could reduce the REE requirement. Neodymium, praseodymium, terbium and dysprosium should be given priority for substitution in pigments. Cerium, lanthanum and yttrium are examples of rare earth elements that are produced in such large excesses that substitution is considered less important. These issues are also listed under waste prevention.	Reduced need for REE
C21	Replacing magnesium with alternative desulfurization materials in steel production	Magnesium is used for desulfurization of steel. Current materials that can in some cases replace magnesium are calcium oxide and calcium carbide.	Reduced need for magnesium
C22	Replacing nickel-steel with chromium-steel alloys	Nickel-steel alloys can in some cases be replaced with chromium steel. However, such substitution may provide less advantageous performance properties for certain purposes.	Reduced need for nickel
C23	Replacing Niobium steel for HSLA steel with other alloy components	Niobium steel alloys for HSLA steels can in some cases be substituted with other steel alloys. However, such substitution may result in less advantageous performance properties for certain applications.	Reduced need for niobium
C24	Replacing PGM materials in EE products with gold	PGM metals in EE products can in some cases be replaced with gold.	Reduced need for PGM-metals
C25	Substituting titanium metal with aluminum alloys in sports products	Titanium metal in consumer products such as sporting goods can in some cases be replaced with aluminum alloys or carbon fiber. However, this may result in reduced performance.	Reduced need for titanium metal

C26	Substitution of gallium with silicon in semiconductor materials and tungsten for lighting	In an acute shortage situation, gallium used in semiconductors could be replaced with silicon. Similarly, gallium in LEDs could be replaced with historical lighting technologies based on, for example, tungsten. However, this would result in significantly lower energy efficiency and product performance.	Reduced need for gallium
C27	Substitution of germanium with silicon in semiconductor materials	Germanium can be replaced to some extent with silicon as a semiconductor material in EE products. However, this will result in significantly lower product performance and size in portable devices.	Reduced need for germanium
C28	Substitution of vanadium with alternative catalyst material in various chemical processes	Vanadium catalysts can be replaced by nickel or PGM metals in some industrial processes. However, both nickel and PGM are also CRMs	Reduced need for vanadium
C29	Consider the possibility of a full transition to digital means of payment	Full transition to digital means of payment will eliminate the need for physical currency in the form of coins that typically contain copper and nickel, as well as banknotes that may also contain CRMs, such as europium.	Reduced CRM-need
C30	Consider the possibility of replacing copper and nickel coatings on ammunition with alternative materials	The copper and nickel coating on ammunition can in some cases be replaced with alternative materials such as wax, plastic or steel.	Reduced needs for copper and nickel

About this publication

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